An Overview of Systems Used for Rating Fire Danger and Predicting Fire Behavior Used in Canada

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Lesson 31
S-590 Advanced Fire Behavior Interpretation Course

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Outline of Presentation

- I. CFFDRS Structure
- II. Fire Weather Index Module or
- III. Subsystem

 Fire Behavior Prediction Module or
- IV. Subsystem
 Selected Wildfire Case Studies
- V. Basic Similarities & Differences Between
- VI. Canadian and U.S. Systems
 Applications, Training & Software
 VII. Closing Comments

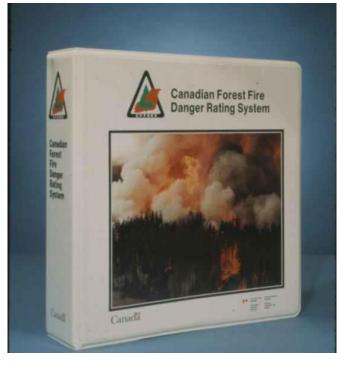






I. CFFDRS Structure

The Canadian Forest Fire Danger Rating System (CFFDRS) is the national system of rating fire danger used in Canada. The CFFDRS includes all the guides to the evaluation of fire danger and the prediction of fire behavior.

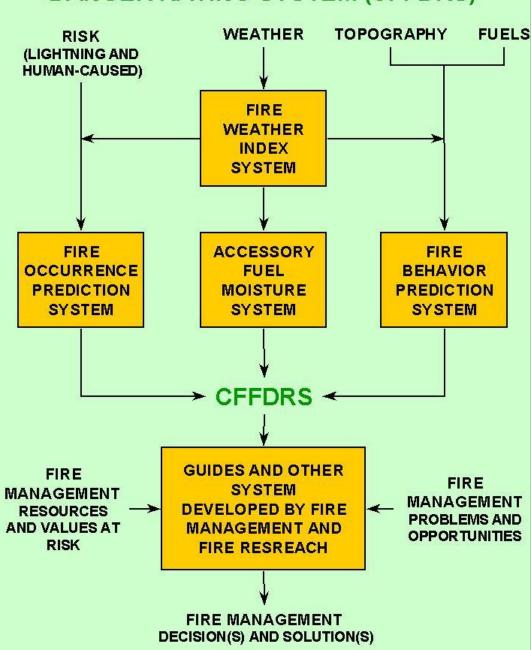


The CFFDRS represents the fifth generation of fire danger rating methods developed in Canada by the federal forestry service.





CANADIAN FOREST FIRE DANGER RATING SYSTEM (CFFDRS)

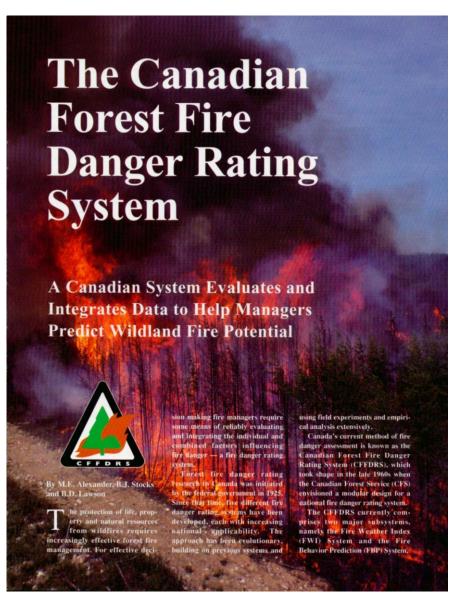


Simplified CFFDRS structure diagram illustrating the linkage to fire management actions

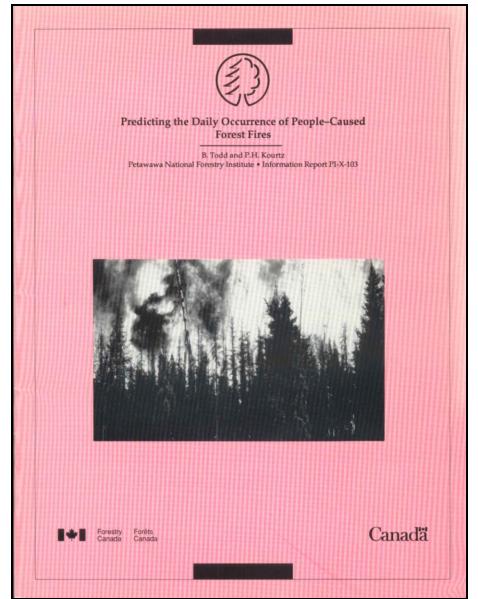


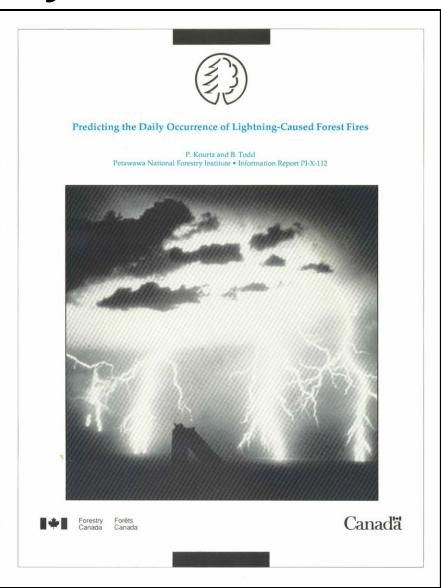
CFFDRSOverview Papers Available



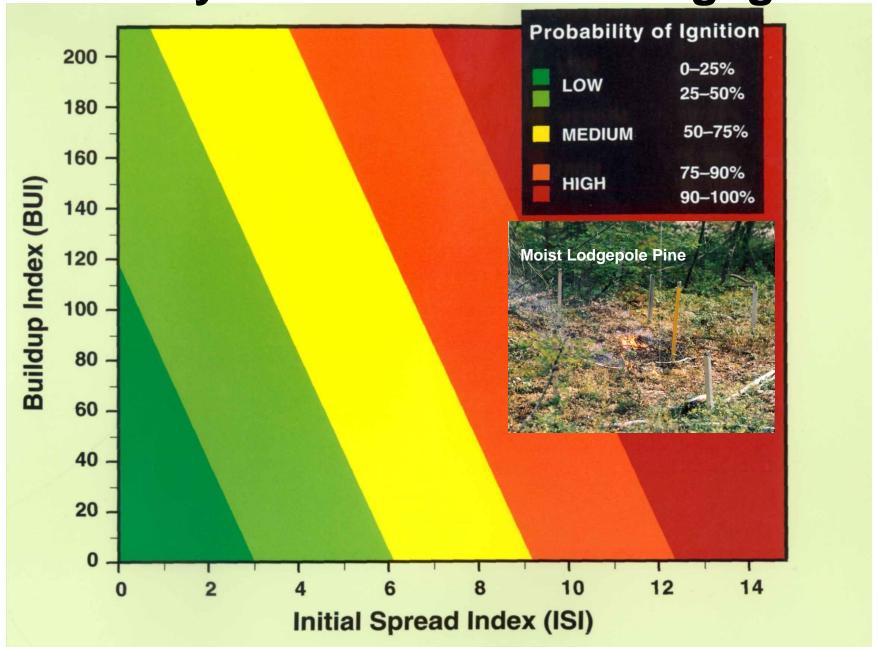


Canadian Forest Fire Occurrence Prediction System

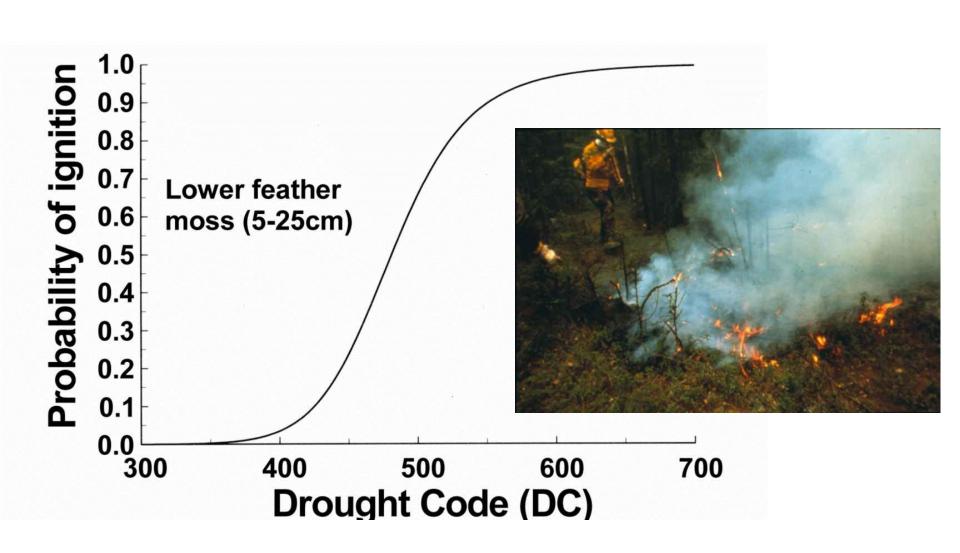




Probability of Sustained Flaming Ignition



Probability of Sustained Smoldering Ignition

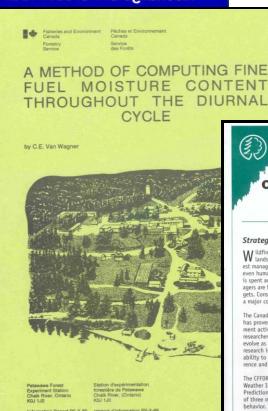


Accessory Fuel Moisture System

FORESTRY FRAME 268

Ground-truthing the Drought Code: Field Verification of Overwinter Recharge of Forest Floor Moisture Purpose: to support applications of other CFFDRS subsystems

NOVEMBER 1996



FORESTRY

DIURNAL VARIATION IN THE FINE
FUEL MOISTURE CODE: TABLES
AND COMPUTER SOURCE CODE

ISSN 0835 0752

February 1996

COLUMBIA PARTNERSHIP AGREEMENT ON FOREST RESOURCE DEVELOPMENT: FRDA

Predicting Forest Floor Moisture
Contents from Duff Moisture Code Values

TECHNOLOGY TRANSFER NOTES

Forestry Research Applications Pacific Forestry Centre No.6 October, 1997

B.D. Lawson, G.N. Dalrymple, B.C. Hawkes

Strategic Importance

W idfires continue to be a dominant force on Canada's landscape, affecting patterns of flora and fauna, forest management activities, resource values, property and even human life. In Canada, approximately \$500 million is spent annually on fire management activities. Fire managers are facing increased demands and diminishing budgets. Consequently, the reliability of predictive models is a major concern.

The Canadian Forest Fire Banger Rating System (CFFDRS) has proven to be a reliable tool in directing fire management activities. Initiated by Canadian Forest Service researchers in the late 1960s, the CFFDRS continues to evolve as new information becomes available. Continued a seatch is required to refine and expand the system's ability to predict various aspects of fire behavior, occur-

The CFFBRS combines two major systems, the Fire Weather Index (FWI) System and the Fire Behavior Prediction (FBP) System. The FWI system is comprised of three moisture codes and three indexes of fire behavior. The moisture codes track the relative moisture content of three forest floor components. A brief summary of the three moisture codes is provided below.

Moisture content' is the main factor controlling a forest fuel's ability to ignite and sustain combustion; a low moisture content means less energy is required to ignite a fuel. The three codes indicate how the moisture content of the different forest floor layers react differently to drying and wetting.

Knowledge of duff moisture content is particularly important to:

- . Start a weather station late in the fire season;
- · Predict smoldering ignition for forest duff types; and,
- Compare the prediction systems for forest floor consumption with those used in other countries.

Duff Moisture Code (DMC)

The DMC is a numerical rating of moderately deep forest floor dryness (basically the soil F layer, also referred to as duff). The flammability of the duff layer is important because duff consumption is one of the main sources of the energy produced in forest fires. The weather factors

Moisture content is defined as the amount of water present in a fuel expressed as a percent of the oven dry weight of the fuel.

+1

Natural Resource

Ressources naturelles Canada Service canadien des forêts



dä

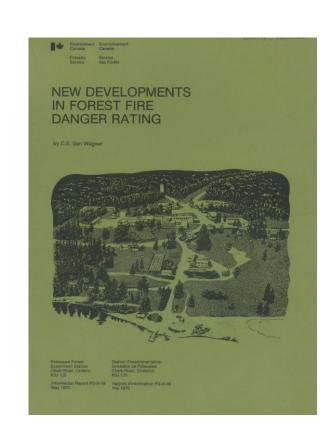


URCE DEVELOPMENT: FRDA II



II. Fire Weather Index Module or Subsystem

Forest fire danger rating is a fascinating but exasperating branch of forest research. The goal is easily stated: Make an index such that any given value will always represent the same fire behavior, no matter what weather history leads up to it.



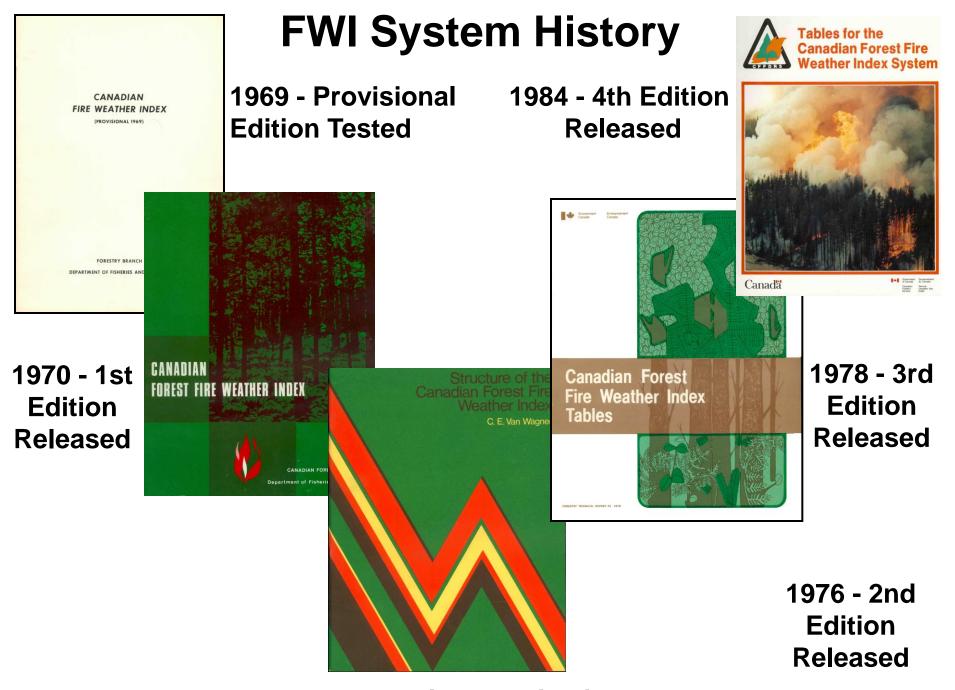
C.E. Van Wagner (1970)





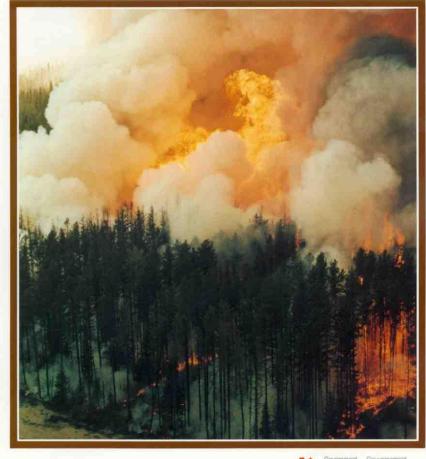






1974 - Technical Publication





Canada

1+

overnment Gouvern Canada du Cana anadian Service

Service canadien de Van Wagner (1987)

publication on

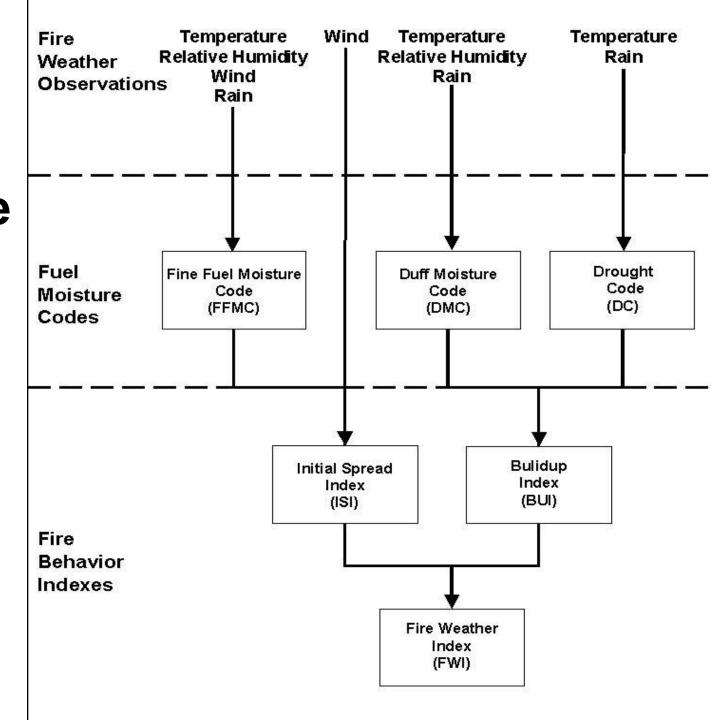
technical
derivation of FWI
System



FWI System is comprised of 31 equations

Structure of the Canadian **Forest Fire** Weather Index (FWI) **System**





The FWI System consists of six standard components that provide relative numerical ratings of wildland fire potential.

The first three components are fuel moisture codes that follow daily changes in the moisture contents of three classes of forest fuel with different drying rates.

For each, there are two phases -- one for wetting and one for drying -- arranged so that the higher values represent lower moisture contents and hence greater flammability

The final three components of the FWI System are fire behavior indexes, representing rate of spread, amount of available fuel, and fire intensity. Their values increase as fire weather severity worsens.

The FWI System is dependent on weather only and does not consider differences in fire risk, or ignition sources fuel or topography *per se*.

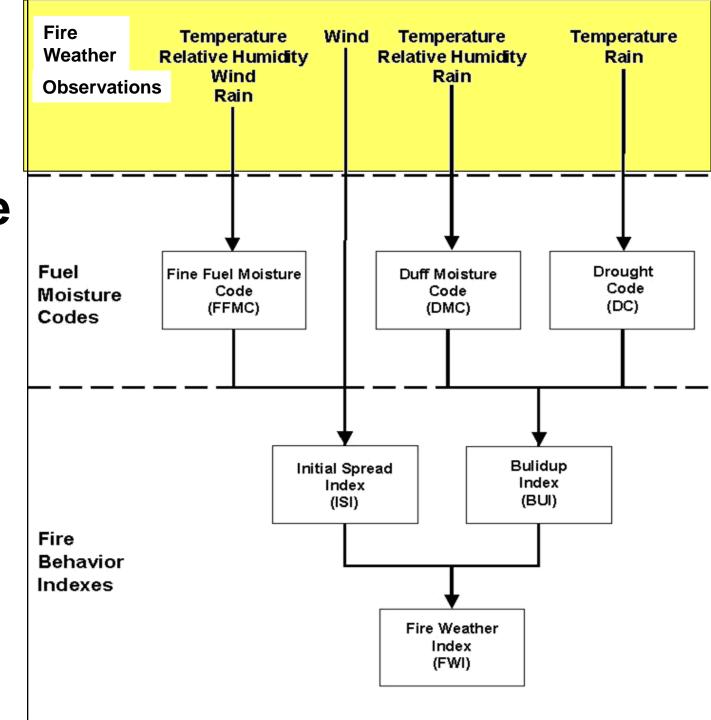
Level terrain and a standard fuel type (mature pine stand) is assumed. The system thus provides a uniform method of rating fire danger across Canada.



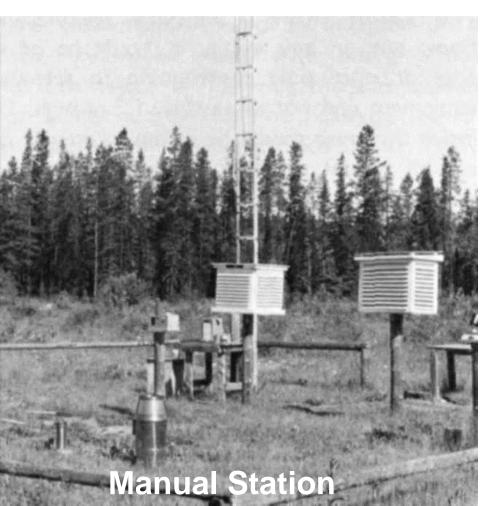
Jack pine and lodgepole pine forests have continental distribution across Canada.

Structure of the Canadian **Forest Fire** Weather Index (FWI) **System**





1200 hours LST Fire Weather Observations





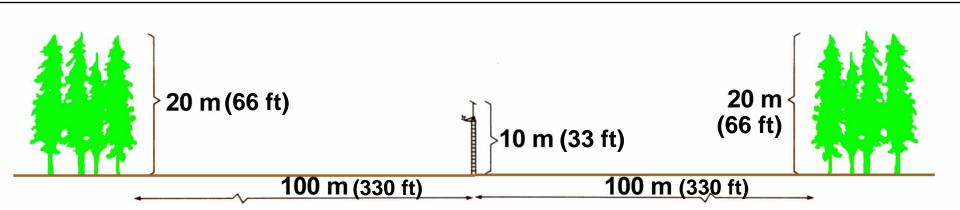
Fire Weather Observations

Dry-bulb Temperature - °C (°F)
Relative Humidity - %
10-m Open Wind Speed - km/h (mph)
24-hr Accumulated Rainfall - mm (in.)

Calculation of the FWI System components is based on consecutive daily fire weather observations. Therefore, an unbroken daily weather record is required.

The 10-m Open Wind Standard in the Canadian Forest Forest Danger Rating System (CFFDRS)

The subsystems of the CFFDRS use a <u>10</u> minute average wind reading taken at a height of <u>10</u> meters (33 ft) above ground in an opening with a diameter <u>10</u> times the height of the surrounding vegetation.







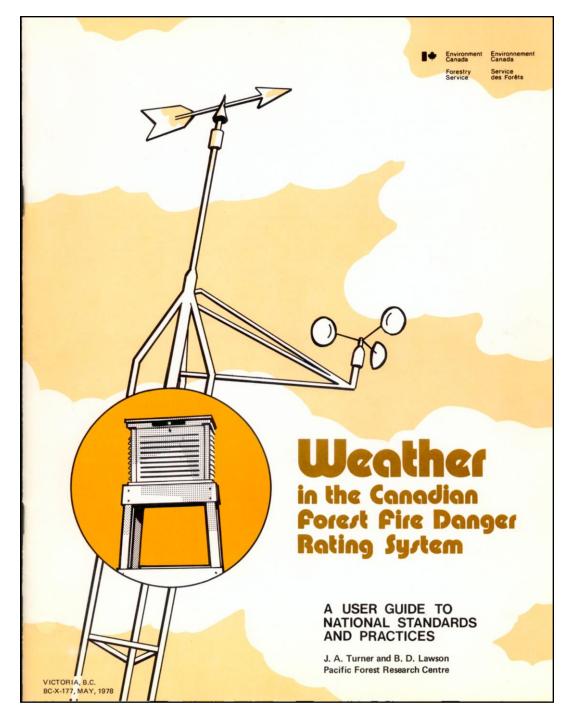


Quality control in fire danger rating





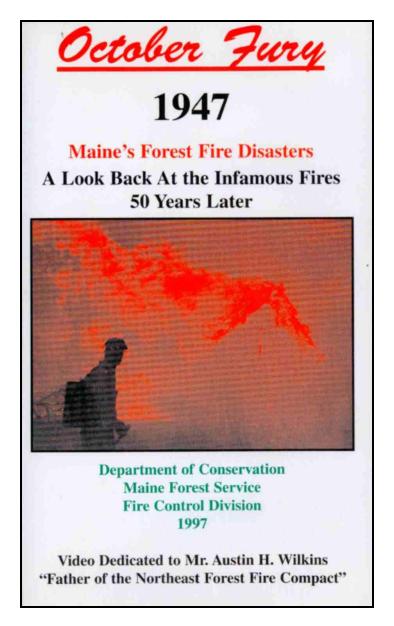
Importance of adhering to fire weather station standards with respect to instrumentation and clearing size.

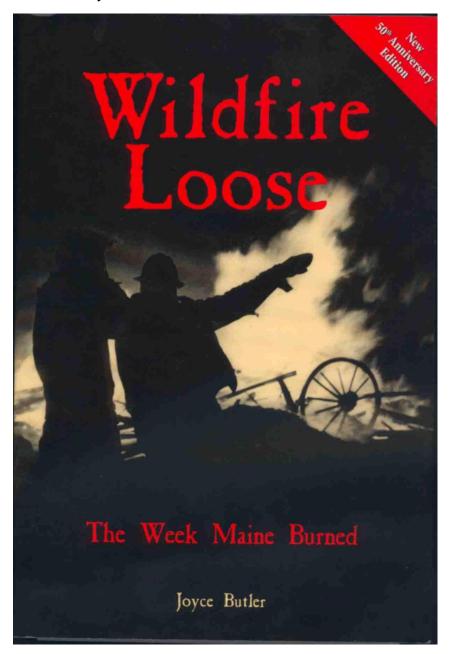


CFFDRS Weather Guide sets out **National Standards** and Practices

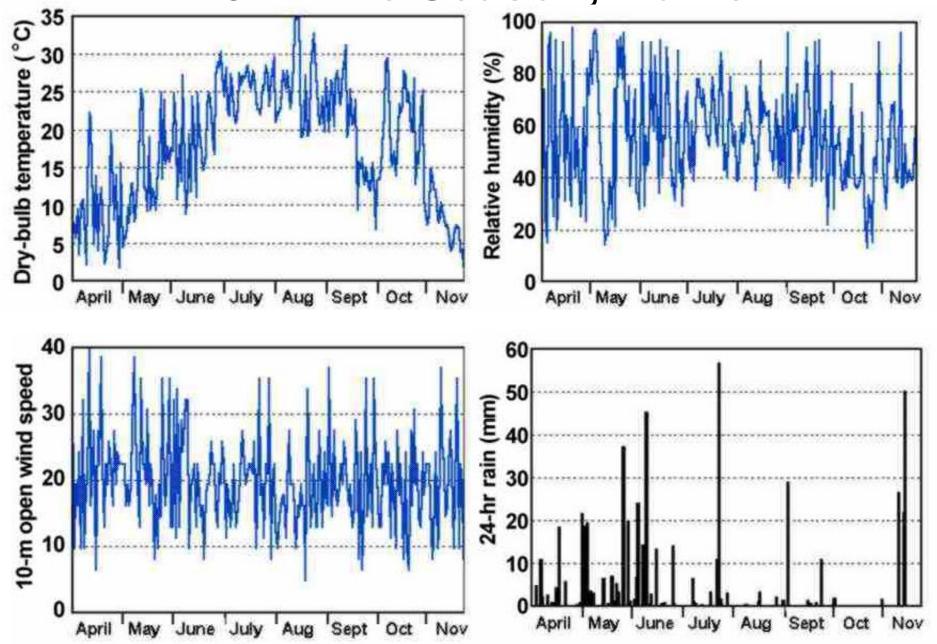


1947 Fire Season, Maine



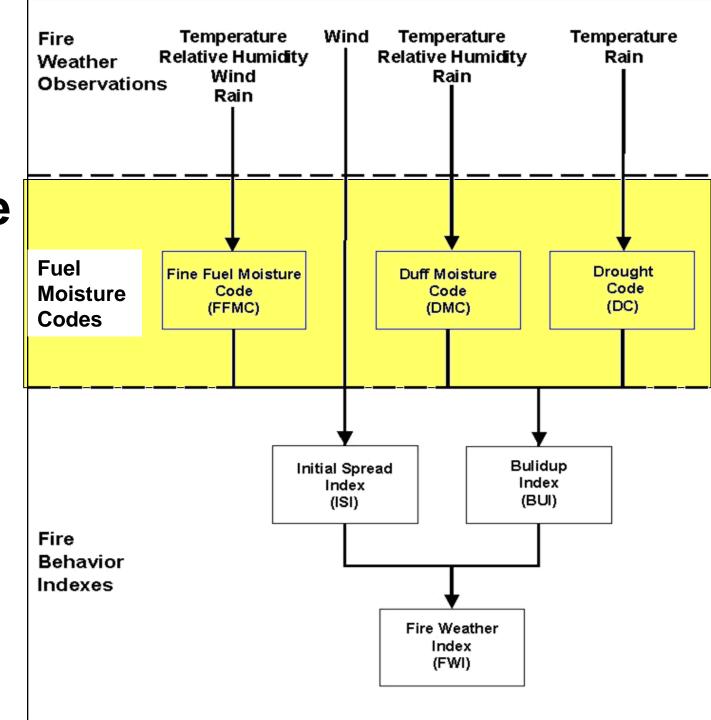


1947 Fire Season, Maine



Structure of the Canadian **Forest Fire** Weather Index (FWI) **System**





The FWI System fuel moisture codes are dynamic "bookkeeping" systems that account for each day's wetting and drying effects.

- Fine Fuel Moisture Code (FFMC)
- Duff Moisture Code (DMC)
- Drought Code (DC)



Starting the Calculations

In regions normally covered by snow during the winter, begin calculations on the 3rd day after snow essentially left the area to which the fire danger rating applies. In regions where snow cover is not a significant feature, begin calculations on the 3rd successive day that noon temperatures of 12 °C (54 °F) or higher have been recorded.

In either case, use the following starting values:

FFMC 85

DMC 6

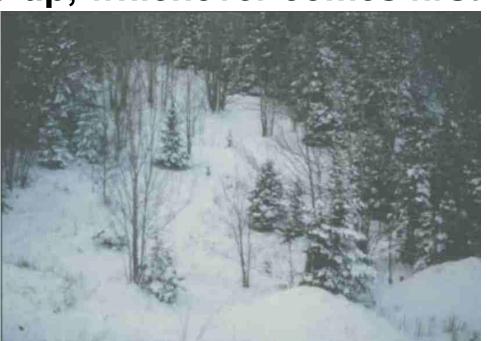
DC 15*

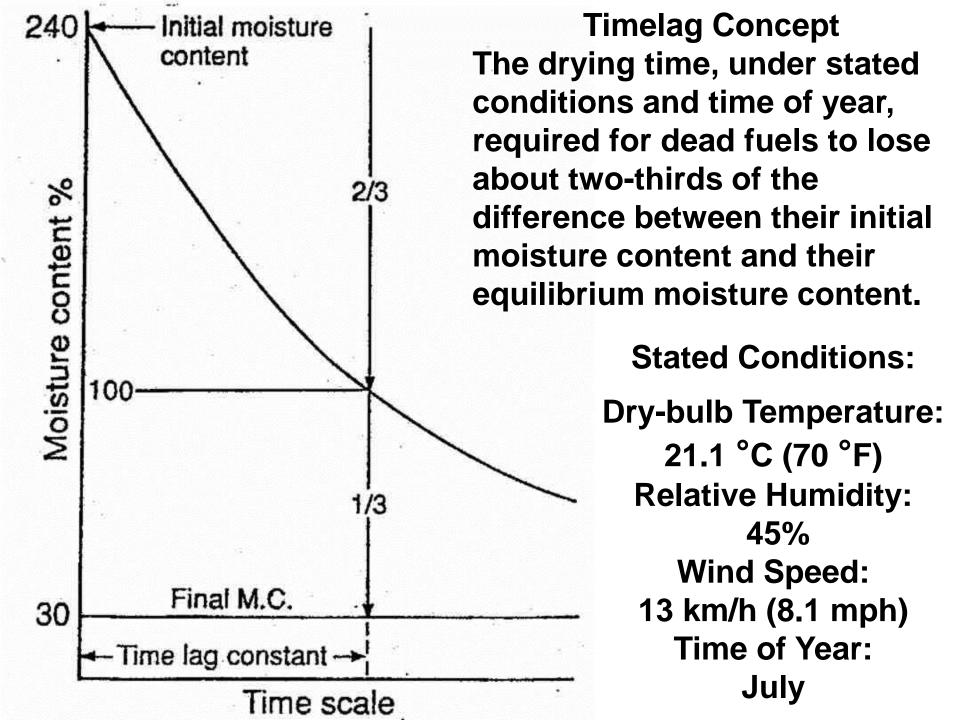
*maybe adjusted upwards for a high fall value/below normal overwinter precipitation.



Ending the Calculations

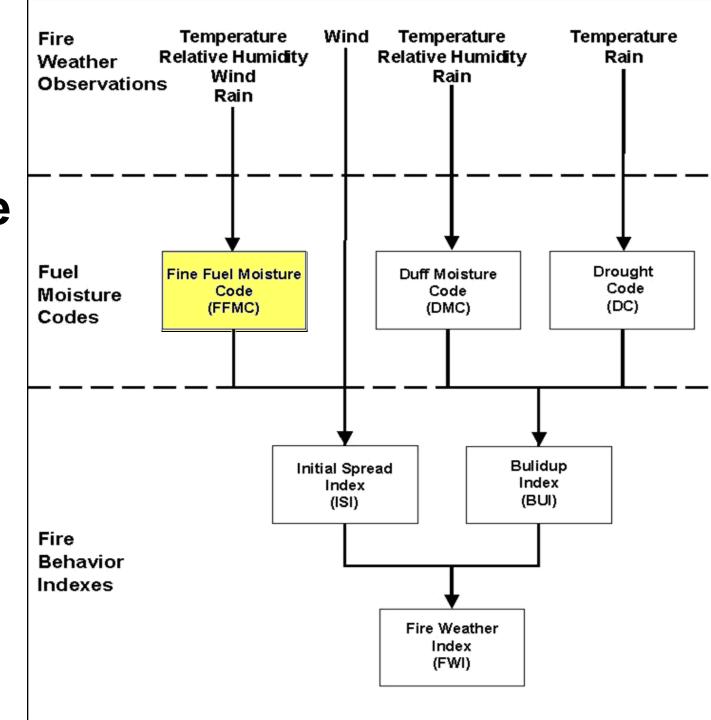
Closing dates for fire danger calculations will normally be supplied by the fire weather authorities. In the absence of such direction, it is recommended that observations and calculations be continued until November 1 *or* continuous snow cover *or* ground freeze-up, whichever comes first.





Structure of the Canadian **Forest Fire** Weather Index (FWI) **System**





Fine Fuel Moisture Code (FFMC)

A numerical rating of the moisture content of litter and other cured fine fuels. This code is an indicator of the relative ease of ignition and flammability of fine fuel.

Weather inputs: Temp, RH, WS, Rain

Scale: 0-101 (fixed)

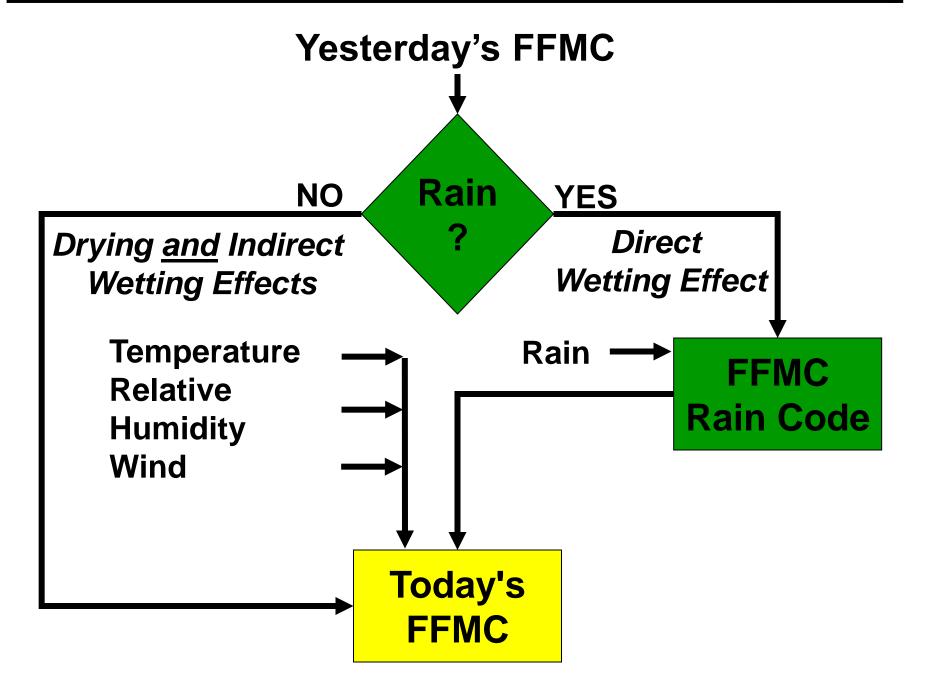
Rainfall threshold: 0.6 mm (0.02 in.)

Timelag: 2/3 day or 16 hours

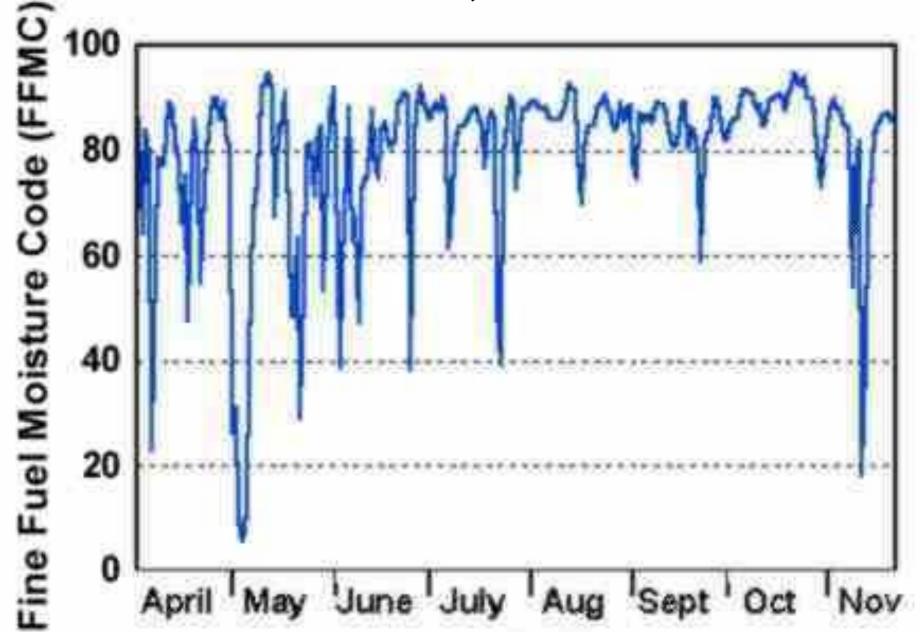
Nominal depth: 1.2 cm (0.5 in.)



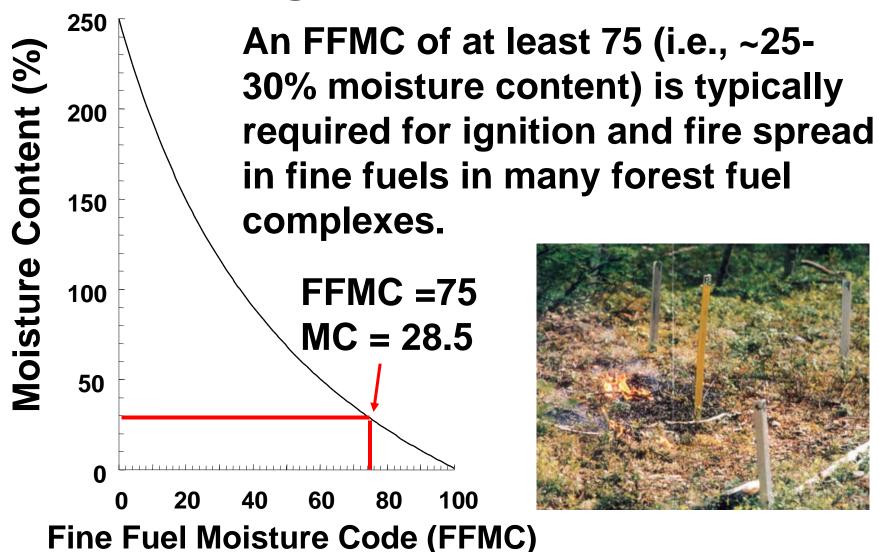
Calculation of the Fine Fuel Moisture Code (FFMC)



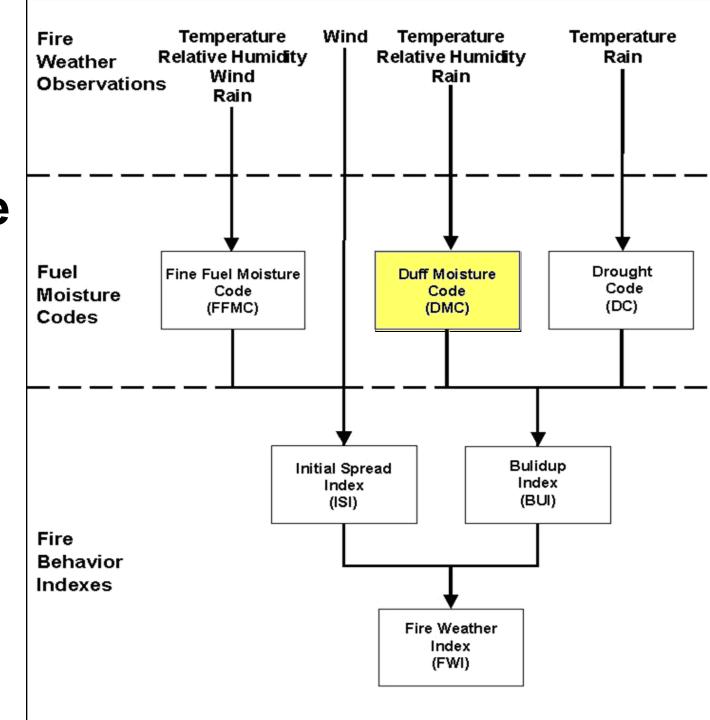
FFMC -Portland, Maine - 1947



Fine Fuel Moisture Code (FFMC) "rough rule of thumb"







Duff Moisture Code (DMC)

A numerical rating of the average moisture content of loosely compacted organic layers of moderate depth. This code gives an indication of fuel consumption in moderate duff layers and medium-sized woody material.

Weather inputs: Temp, RH, Rain

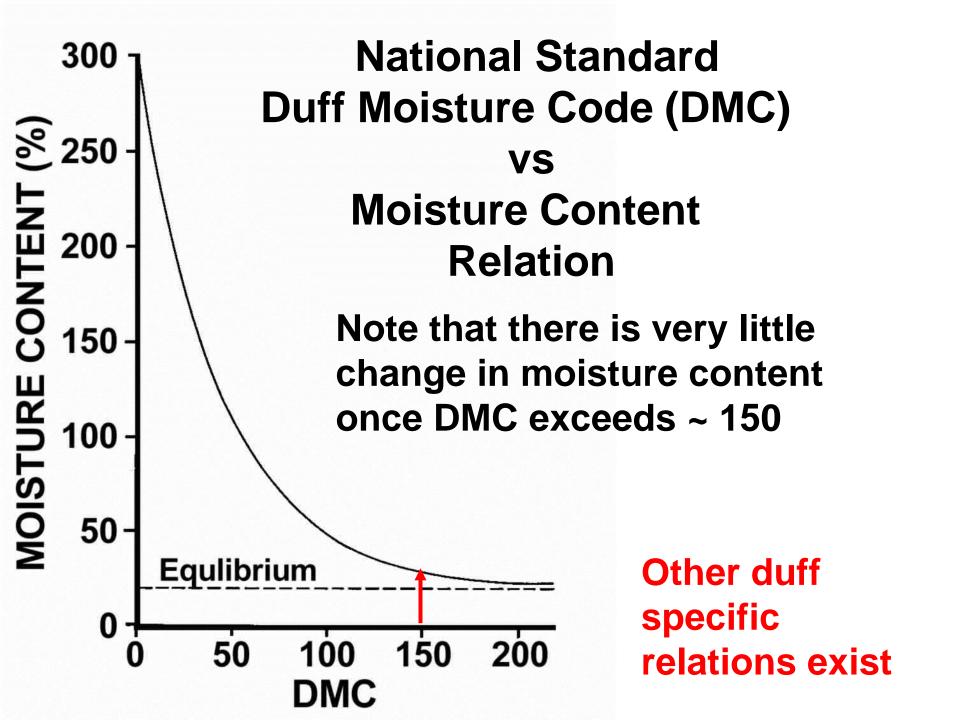
Scale: technically open ended

Rainfall threshold: 1.5 mm (0.06 in.)

Timelag: 15 days

Nominal depth: 7.0 cm (2.8 in.)



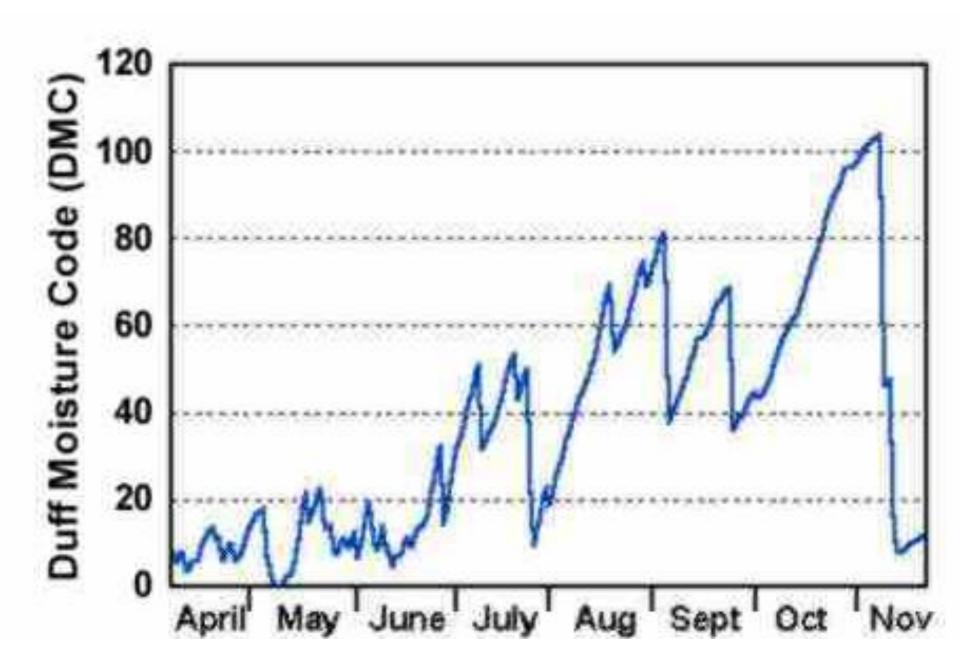


Seasonal Variation in DMC Drying

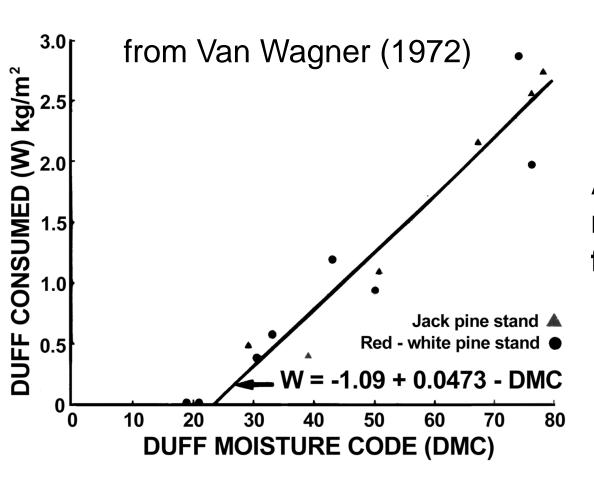
| FF MOISTUR | RE CODE | | DMC | | | | | | | | |
|-------------|-----------------|----------|-------|-------|------|--------|--------------|--------|-------------|---------|--------|
| Temperature | RH (%) | Month | | | | | | | | | |
| (°C) | | February | March | April | May | June | July | August | September | October | Novemb |
| | | | | | | Drying | Factor | | | | |
| | 0-32 | 3 | 3 | 5 | 5 | 5 | 4 | 4 | 3 | 3 | 2 |
| | 33-52 | 2 | 2 | 3 | 4 | 4 | 3 | 3 | 3 2 2 | 2 | 2 |
| 711 6 76 | 53-73 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 |
| | 74-100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 0-27 | 3 | 4 | 6 | 6 | 6 | 5 | 5 | 4 | 3 | 3 |
| | 28-42 | 3 | 3 | 5 | 5 | 5 | 4 | 4 | 3 | 3 | 2 |
| | 43-58 | 2 | 2 | 3 | 4 | 4 | 3 | 3 | 3 | 2 | 2 |
| | 59-73 | l ī | 2 | 2 | 3 | 3 | 2 | 2 | 2 | 1 | 1 |
| | 74-100 | 1 | 1 | Γhρ | lon | gth | of t | ho / | day | 1 | 1 |
| | 0-22 | 4 | 5 | 1116 | | gui | Oi t | | uay | 4 | 4 |
| | 23-37 | 3 | 4 | | mfl. | iend | 100 | 4ha | | 4 | 3 |
| 30.5-35 | 38-53 | 3 | 3 | | | はこし | L C D | uie | | 3 | 2 2 |
| | 54-68 | 2 | 2 | | | | | | | 2 | 2 |
| | 69-100 | 1 | 1 | du | rati | on (| of d | ryir | ng | 1 | 1 |
| | 0-17 | 5 | 6 | 8 | 9 | 9 | 8 | 7 | 6 | 5 | 5 |
| | 18-29 | 4 | 5 | 7 | 8 | 8 | 7 | 6 | 5 | 4 | 4 |
| THE E | 30-41 | 4 | 4 | 6 | 7 | 7 | 6 | 5 | 4 | 4 | 3 |
| ≥33.3 | 42-53 | 3 | 3 | 5 | 5 | 5 | 5 | 4 | 4 | 3 | 3 |
| | | | | | | | | | | | |
| | 54-65 66-100 | 2 2 | 3 2 | 4 | 4 3 | 4 | 4 | 3 | 3 2 | 2 | 2 2 |

Calculation of the Duff Moisture Code (DMC) Yesterday's DMC Rain NO YES **Drying** Direct **Effect** Wetting Effect **Temperature** Rain **DMC** Relative Rain Code **Humidity Month DMC** Drying **Factor Today's DMC**

DMC - Portland, Maine - 1947



Duff Moisture Code (DMC) "rough rule of thumb"



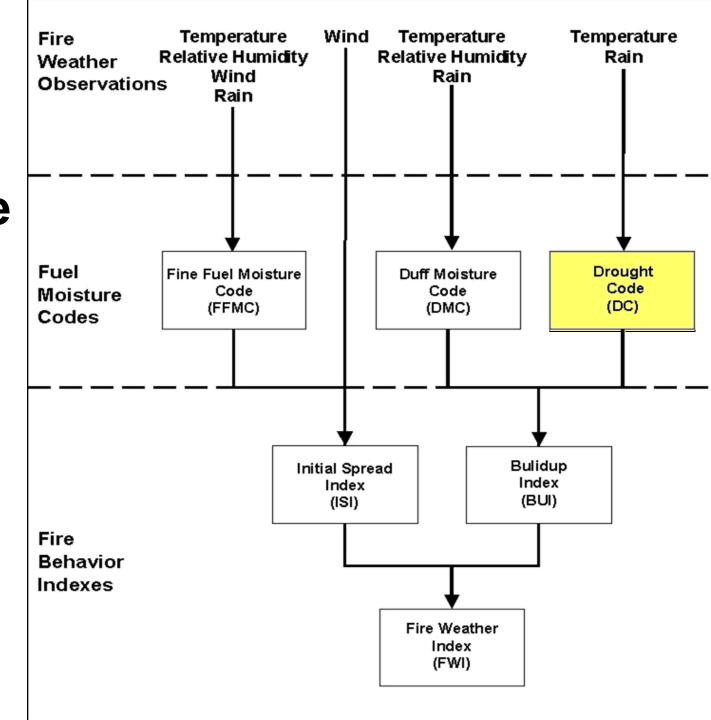
Duff doesn't normally become involved in combustion until the DMC reaches ~ 20.



A DMC of 20 is also regarded as a threshold for lightning fire starts.







Drought Code (DC)

A numerical rating of the average moisture content of deep, compact, organic layers. This code is a useful indicator of seasonal drought effects on forest fuels, and amount of smoldering in deep duff layers and large logs.

Weather inputs: Temp, Rain

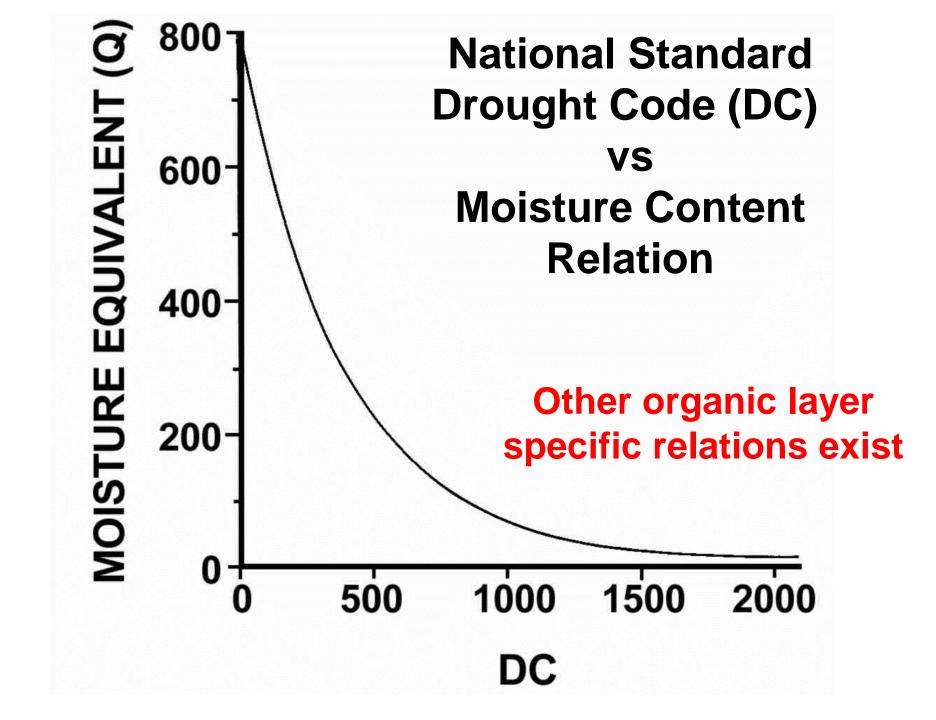
Scale: technically open ended

Rainfall threshold: 2.9cm (0.11 in.)

Timelag: 53 days

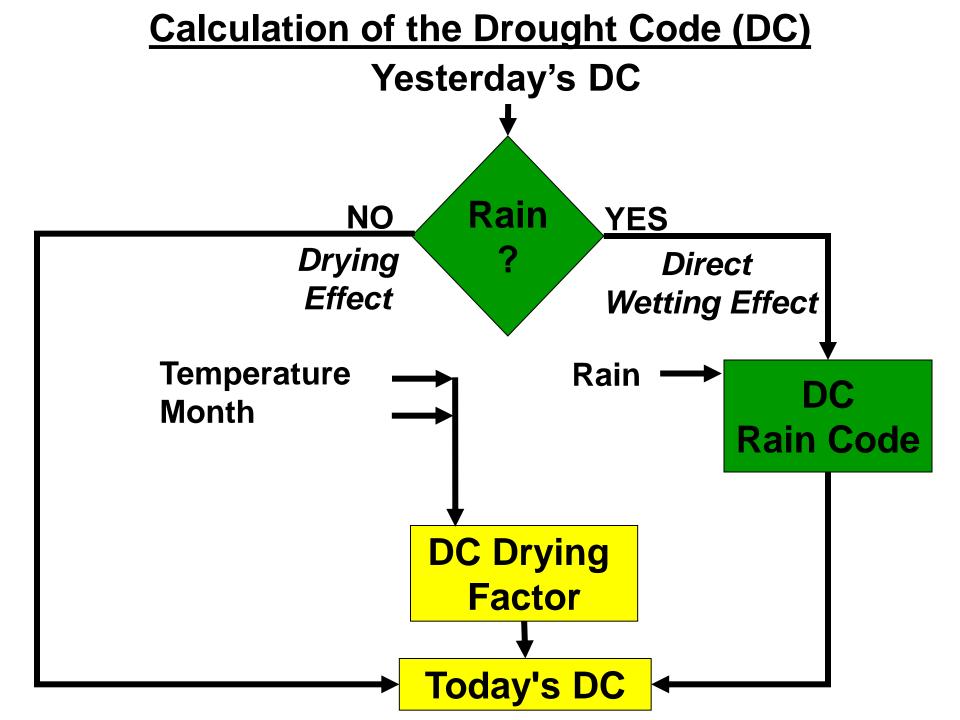
Nominal depth: 18 cm (7.1 in.)





Seasonal Variation in DC Drying

| E | | | | | DC | | | | | | TABLE | |
|---------|------------------------|---|--|---------------------------------|--|---|--|---|---|---|--|--|
| Month | | | | | | | | | | | | |
| January | February | March | April | May | June | July | August | September | October | November | Decemb | |
| | | | | | Drying | Factor | | | | | | |
| 4 | 4 | 4 | 5 | 6 | 7 | 8 | 7 | 6 | 5 | 4 | 4 | |
| 4 | 4 | 4 | 5 | 7 | 8 | 8 | 7 | 6 | 5 | 4 | 4 | |
| 4 | 4 | 4 | 5 | 7 | 8 | 8 | 8 | 6 | 5 | 4 | 4 | |
| 5 | 5 | 5 | c | 7 | 0 | 0 | Q | 7 | 6 | 5 | 5 | |
| 5 | 5 | 5 | Th | e le | ngtl | h of | f the | e da | у | 5 | 5 | |
| 5 | 5 | 5 | influences the | | | | | | | 5 | . 5 | |
| 6 | 6 | 6 | Ь | ura | tion | of | drvi | na | | 6 | 6 | |
| 6 | 6 | 6 L | <u> </u> | J | 10 | 10 | ary i | 1.9. | | 6 | 6 | |
| 6 | 6 | 6 | 8 | 9 | 10 | 10 | 10 | 8 | 7 | 6 | 6 | |
| 7 | 7 | 7 | 8 | 9 | 10 | 11 | 10 | 9 | 8 | 7 | 7 | |
| | January 4 4 5 5 6 6 6 | January February 4 4 4 4 5 5 5 5 5 6 6 6 6 6 6 | January February March 4 4 4 4 4 4 4 4 4 5 5 5 5 5 5 5 5 5 6 6 6 6 6 6 6 6 6 6 6 6 | January February March April 4 | January February March April May 4 4 4 5 6 4 4 4 5 7 4 4 4 5 7 5 5 5 5 The leading 5 5 5 5 inf 6 6 6 6 6 6 6 6 8 9 | January February March April May June | January February March April May June July | January February March April May June July August | January February March April May June July August September | January February March April May June July August September October | January February March April May June July August September October November | |



Flow chart of spring Drought Code (DC) starting value determination

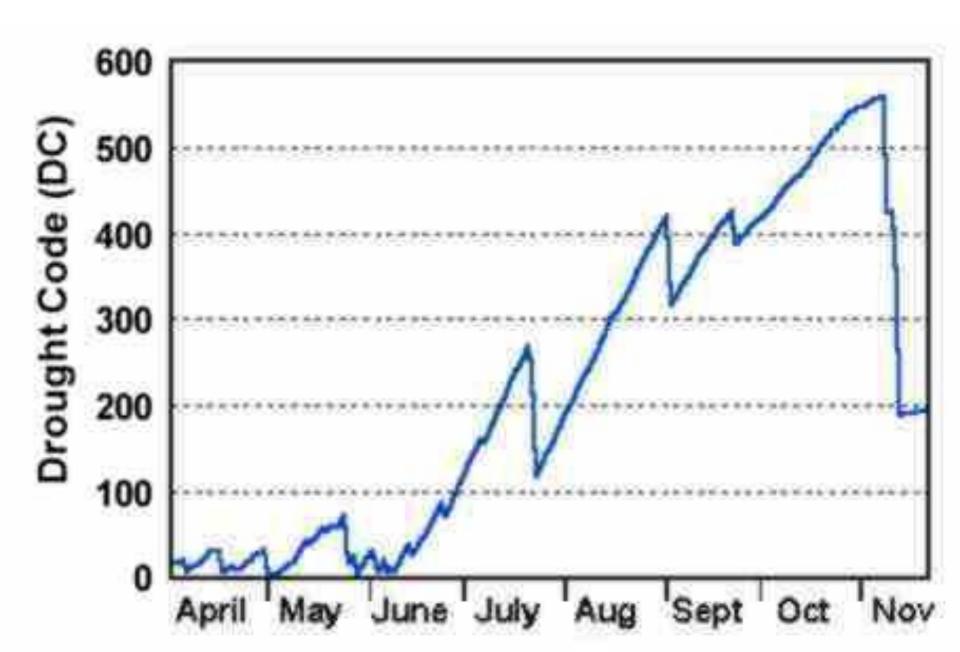
Fall DC value and date of last calculation

Keep record of cumulative precipitation amount for the period between date of last DC calculation the previous fall and spring starting date of calculations.

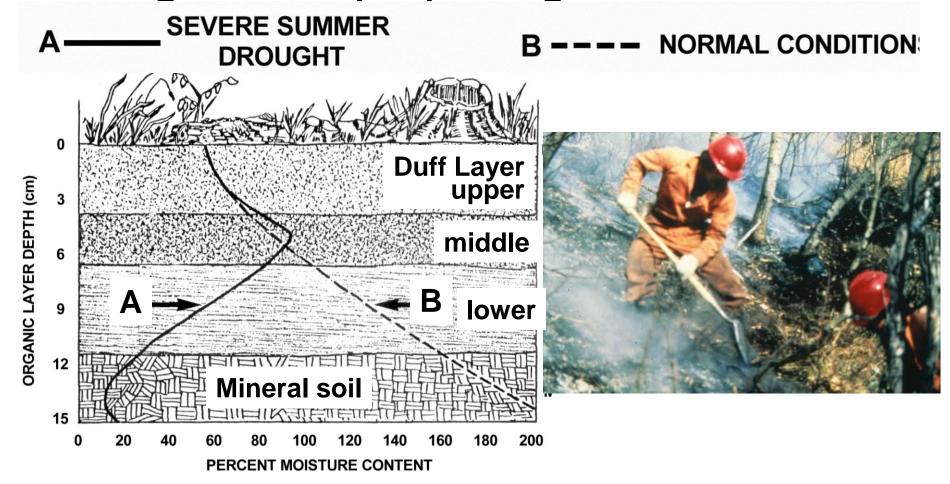
Select values for carry-over fraction of fall moisture and precipitation effectiveness fraction.

Determine spring DC starting value based on fall DC, total overwinter precipitation (mm water equivalent)

DC - Portland, Maine - 1947



Drought Code (DC) "rough rule of thumb"



In many forest fuel complexes a DC of around 300 is generally considered a critical point or threshold for the onset of significant ground or sub-surface fire persistence or activity and in turn mop-up problems.

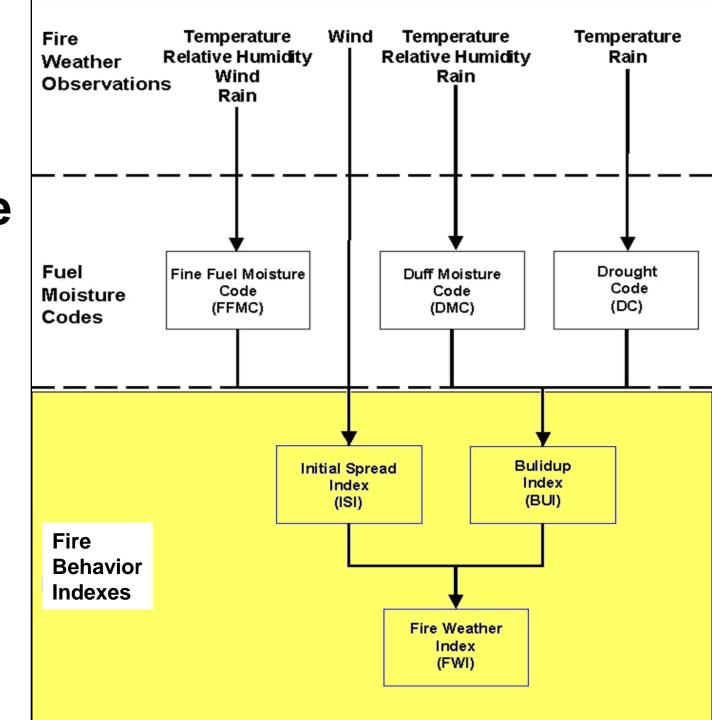
FWI System Fuel Moisture Codes - "Memories"

FFMC - integrates weather effects of past several days

DMC - integrates weather effects over past couple of weeks

DC - integrates temperature and rainfall trend over period of months



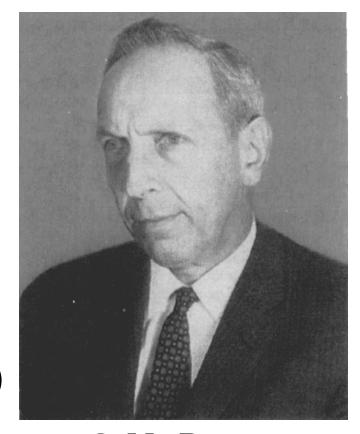


The FWI System fire behavior indexes are patterned after the Bryam's fire intensity concept.

$$I = H \cdot W \cdot I'$$
 \uparrow

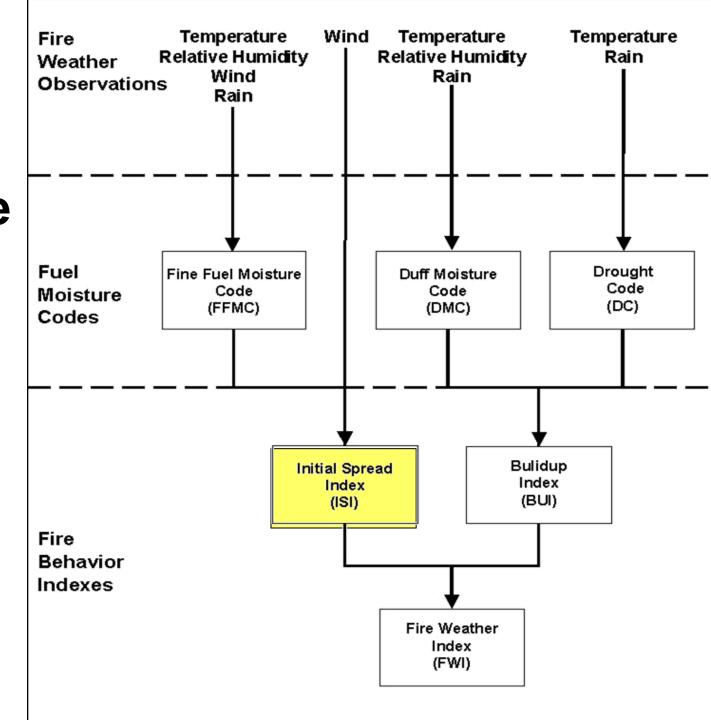
FWI constant BUI ISI

- Initial Spread Index (ISI)
- Buildup Index (BUI)
- Fire Weather Index (FWI)



G.M. Bryam





Initial Spread Index (ISI)

A numerical rating of the expected rate of fire spread. It combines the effects of wind and FFMC on rate of spread without the influence of variable quantities of fuel.

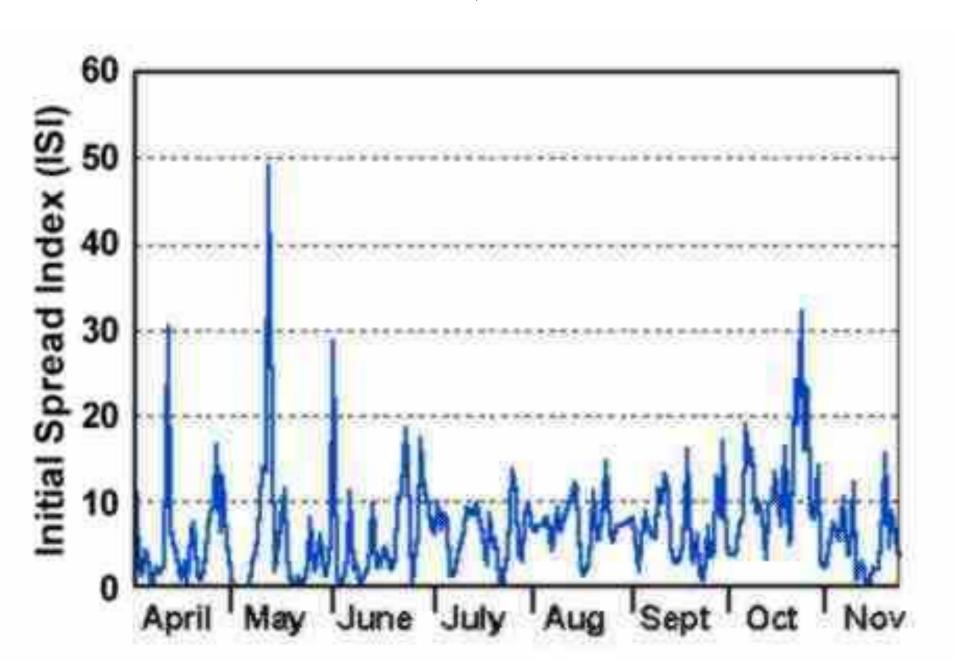
Inputs: FFMC, WS

Scale: technically open ended

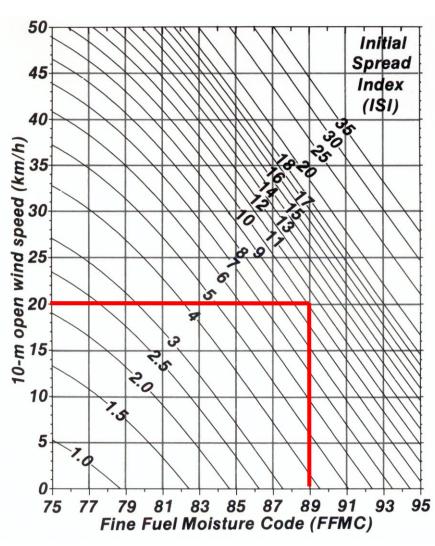
ISI doubles for ever 14 km/h (8.7 mph) increase in wind speed

Of note: Lacks long-term effect of heavy fuel dryness. Best used as a correlator against actual head fire rate of spread in specific fuel types.

ISI - Portland, Maine - 1947



Initial Spread Index (ISI) "rough rule of thumb"

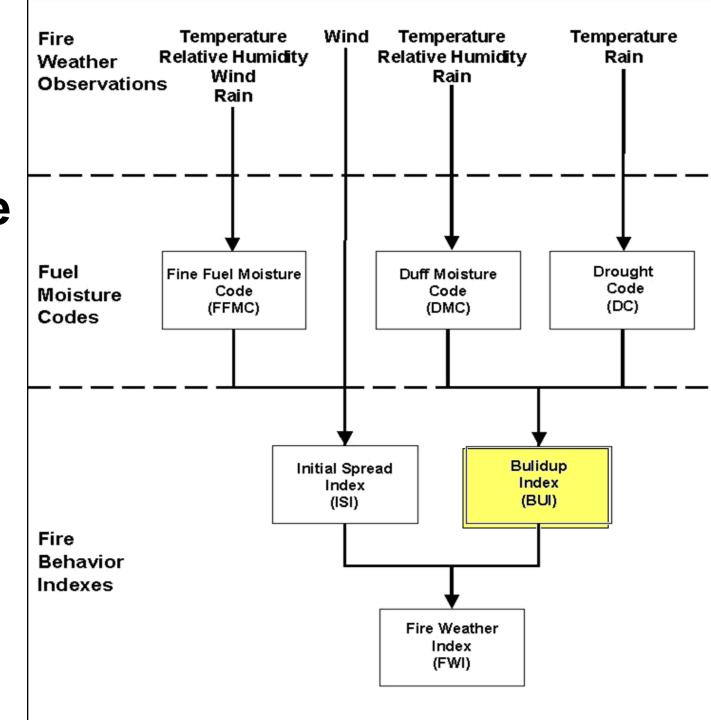


ISI is a function of the FFMC and 10-m open wind. An FFMC of 89 and wind of 20 gives an ISI of 10.



Double digits (i.e., ISI > 10)
generally constitutes a
significant threshold in
most forest fuel complexes.





Buildup Index (BUI)

A numerical rating of the total amount of fuel available for combustion that combines DMC and DC.

Inputs: DMC, DC

Scale: technically open ended



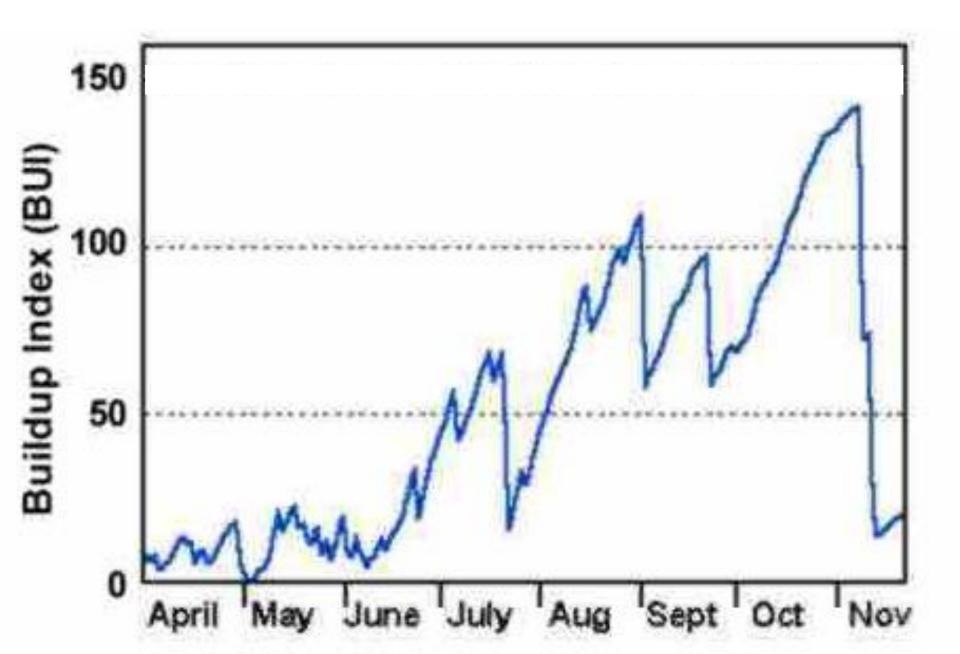
Of note: Compound measure of duff and heavy fuel dryness. Integrates medium and long-term weather history. Good indicator of fire potential over wide areas. Best used as a correlator against actual fuel consumption in specific fuel types.

Buildup Index (BUI)

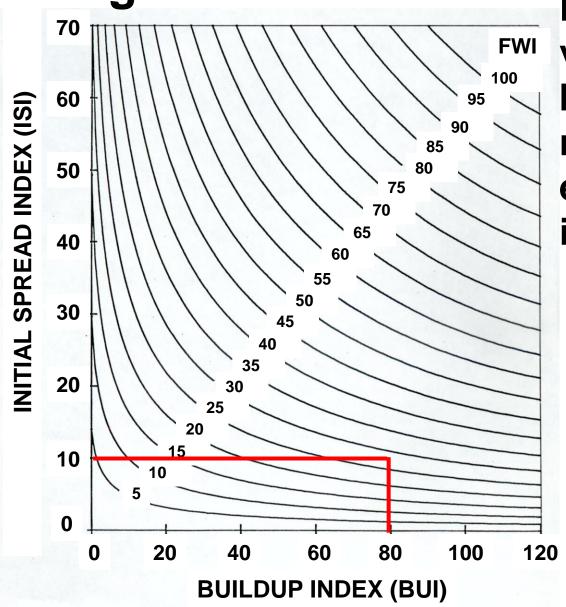
The BUI was constructed so that when the DMC is near zero the DC would not affect daily fire danger (except for smoldering potential) no matter what the DC level in the tabulation as shown below (i.e., when the DMC is near zero, so is the BUI, no matter what the DC value).

| | DC | | | | | | | | | | | |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--|--|--|
| DMC | 0 | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | | | |
| 20 | 20 | 27 | 32 | 34 | 36 | 36 | 37 | 37 | 38 | | | |
| 40 | 40 | 40 | 53 | 60 | 64 | 67 | 68 | 70 | 71 | | | |
| 60 | 60 | 60 | 69 | 80 | 87 | 92 | 96 | 99 | 101 | | | |
| 80 | 80 | 80 | 80 | 96 | 107 | 114 | 120 | 124 | 128 | | | |
| 100 | 100 | 100 | 100 | 109 | 123 | 133 | 141 | 147 | 152 | | | |

BUI - Portland, Maine - 1947



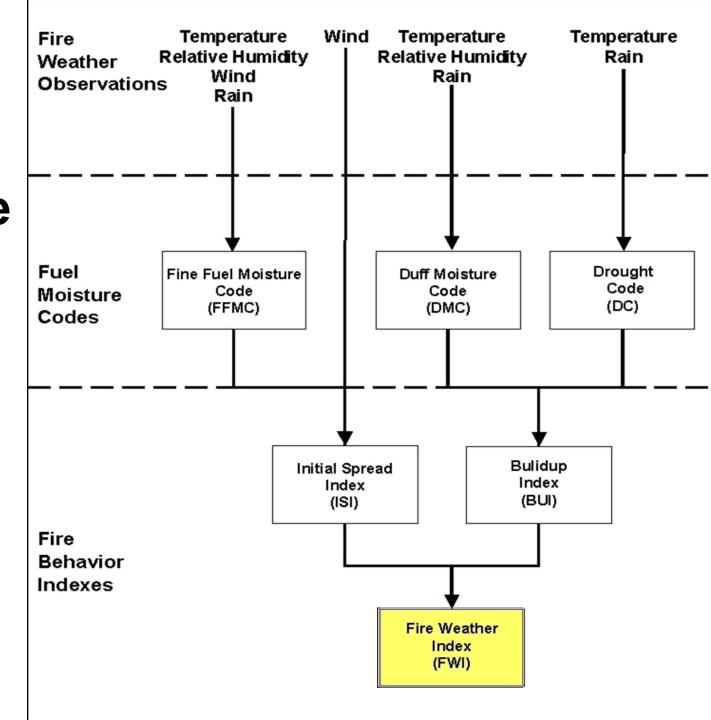
Buildup Index (BUI)
"rough rule of thumb"



In most boreal forest fuel complexes, a BUI > 80 represents a very significant level because given a nominal ISI of 10, extreme fire behavior is in turn quite likely.







Fire Weather Index (FWI)

A numerical rating of fire intensity that combines ISI and BUI. It is suitable as a general index of fire danger throughout the forested areas of Canada.

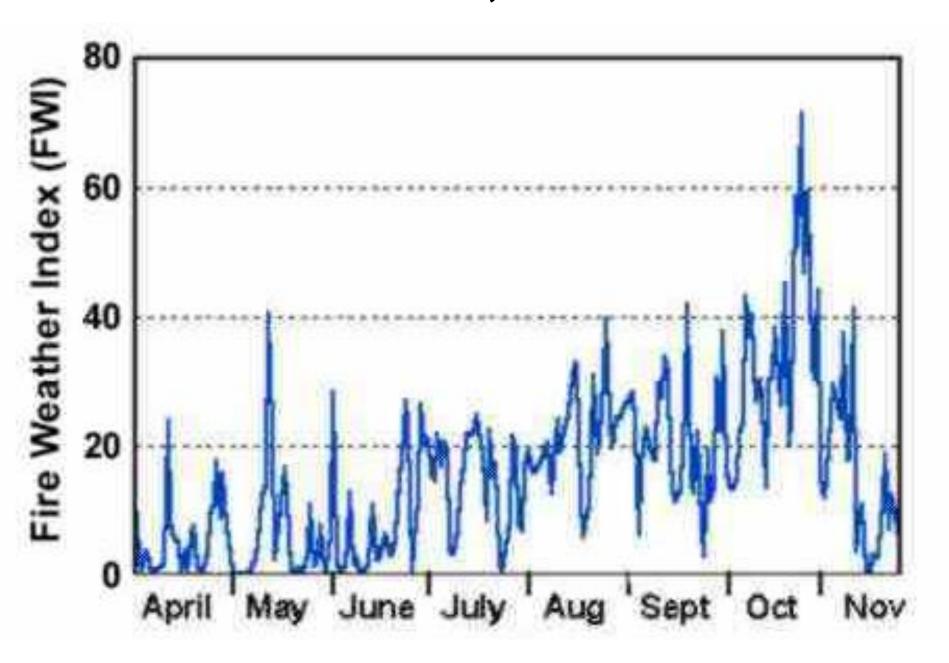
Inputs: ISI, BUI



Scale: technically open ended

Of note: Complex series of effects blended into one number. Integrates effects of weather history and current weather on fire behavior potential. Good correlator against fire intensity in a number of fuel types.

FWI - Portland, Maine - 1947









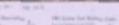


Plate 6

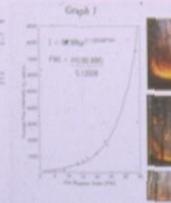




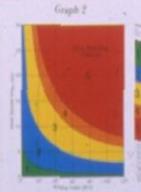


Place 5

Table 1







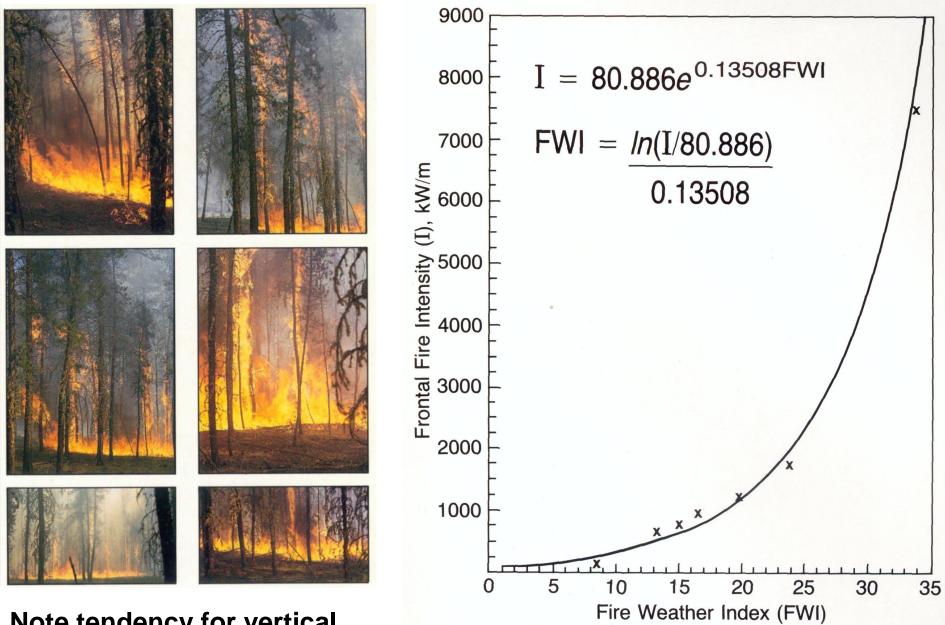








FWI 24



Note tendency for vertical fire development



Informing the Public of Impending Fire Danger

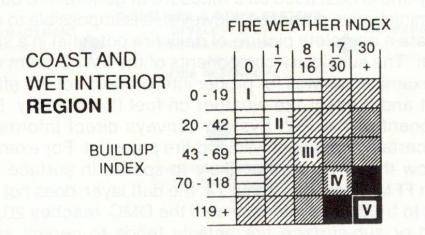


Yukon Territory

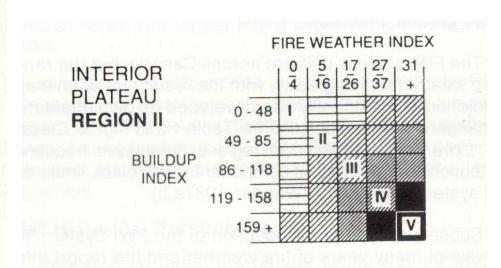
Fire Danger Classification Schemes Used in Canada (exclusive of British Columbia)

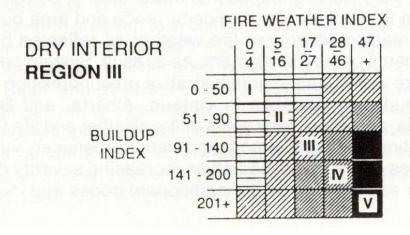
| Province | / | F | ire Dan | ger Class | |
|------------------|-------|------------------|----------|-----------|----------------|
| Territory | Low N | l oderate | High \ | ery High | Extreme |
| | | Fire We | ather In | dex (FWI) | |
| YT | 0-13 | 14-23 | 24-28 | - | 29+ |
| NT | 0-4 | 5-12 | 13-18 | 19-23 | 24+ |
| AB | 0-4 | 5-10 | 11-18 | 19-29 | 30+ |
| SK | 0-5 | 6-16 | 17-30 | - | 31+ |
| ON | 0-3 | 4-10 | 11-22 | - | 23+ |
| QC | 0-4 | 5-10 | 11-20 | - | 21+ |
| NB | 0-1 | 2-8 | 9-15 | 16-21 | 22+ |
| NS | 0-3 | 4-10 | 11-23 | - | 24+ |
| NF | 0-5 | 6-13 | 14-20 | - | 21+ |

B.C. FIRE DANGER REGIONS PRINCE GEORGE VANCOUVER VICTORIA



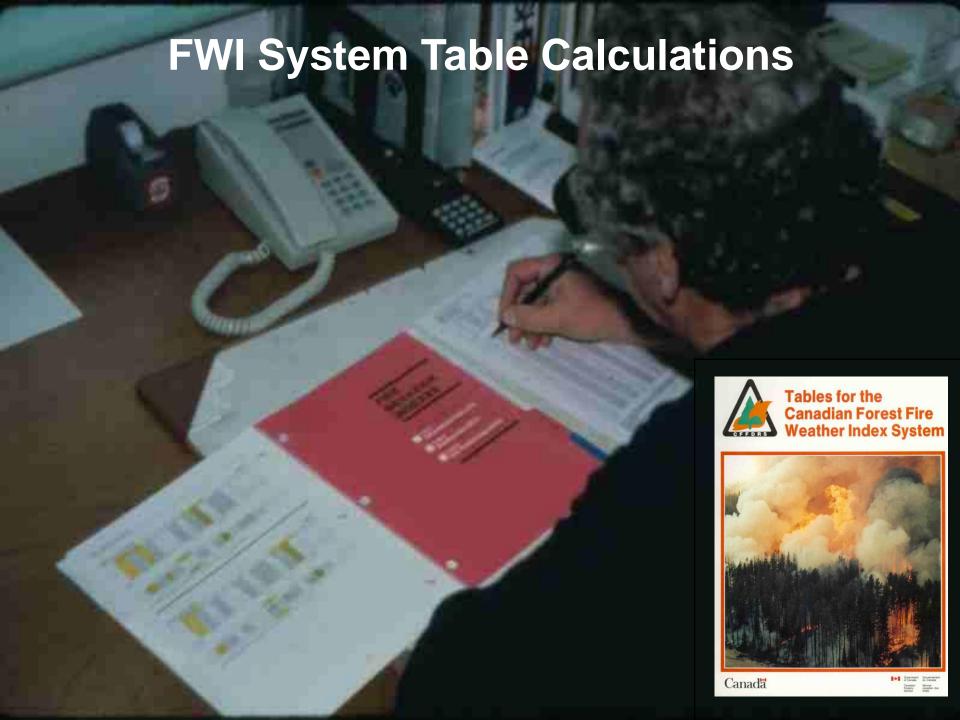
Fire Danger Classification Scheme Used in British Columbia

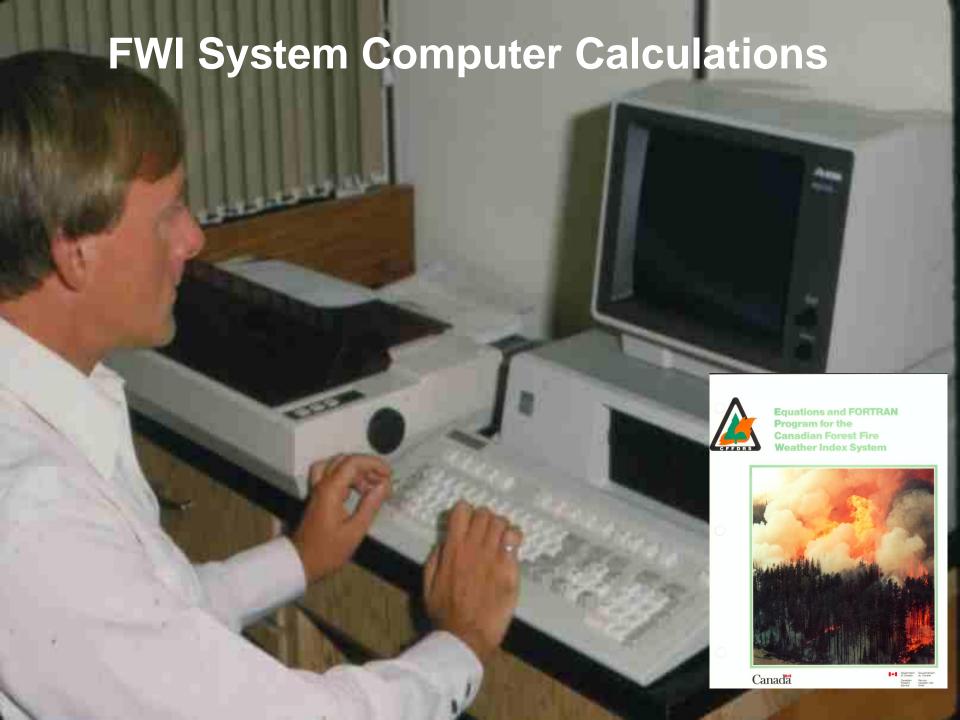




Because the FWI System was developed to portray the influence of weather on fire behavior in a stylized fuel complex, on level terrain, the same component value will obviously have different meanings among fuel types.

| Fuel Type | Aspen Slash | Jack Pine Slash |
|--------------------|-------------------|---------------------|
| ISI | 18 | 18 |
| Spread Rate | 2.5 m/min | 37 m/min |
| | (0.8 ft/min) | (11.5 ft/min) |
| FWI | 23 | 23 |
| Fire Intensity | 2970 kW/m | 67,920 kW/m |
| | (1859 Btu/sec-ft) | (19,635 Btu/sec-ft) |





Fire Weather/Fire Danger Forecasting Example

Today's FWI System Ratings

FFMC 87 DMC 36 DC 200 ISI 6 BUI 50 FWI 15

Fire Danger Class: MODERATE

Fire Weather/Fire Danger Forecasting Example

Tomorrow's Forecasted Weather

Temp 77 °F RH 30% Wind 15.5 mph Rain none



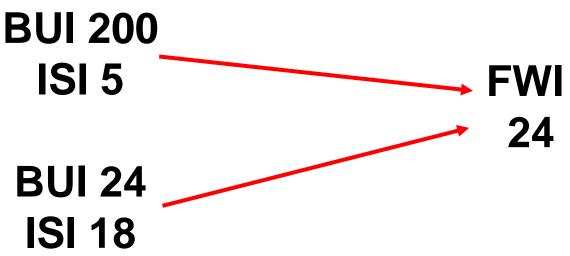
Tomorrow's FWI System Ratings

FFMC 90 DMC 40 DC 208 ISI 15 BUI 56 FWI 32

Fire Danger Class: EXTREME

Different ISI and BUI combinations can result in the same FWI.

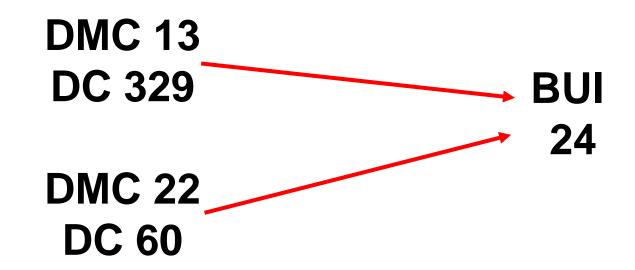
For example:



Fires occurring under the conditions stated above would no doubt produce similar frontal intensities (assuming the same ground slope and fuel type). However, the resulting fire growth (fire's size) and mop-up (fire's persistence) requirements would undoubtedly be quite different.

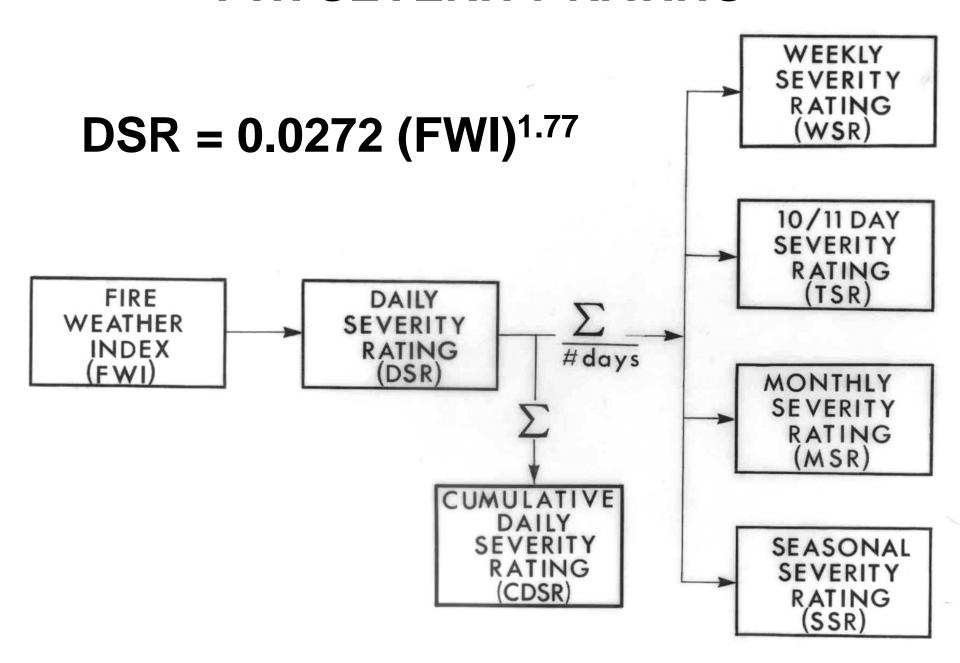
Different DMC and DC combinations can result in the same BUI.

For example:



In cases where a low BUI is involved, one needs to check for a high DC.

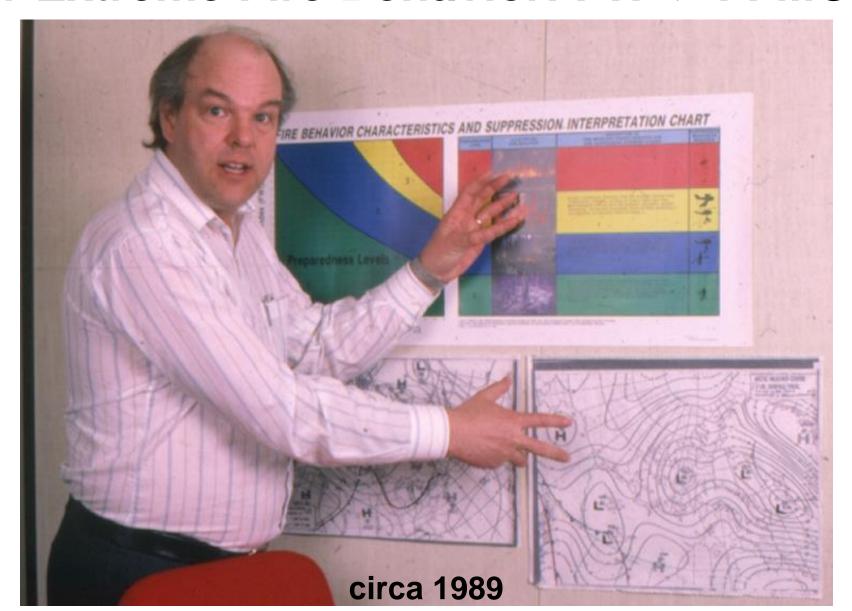
FWI SEVERITY RATING



"Operationalizing" of the FWI System components

- Personal experience linking indices to wildfire & prescribed fire activity
- Examining historical summaries
- Historical wildfire & prescribed fire case studies
- Comparison to statistical data from fire reports
- Recent wildfire case studies
- Experimental & operational burning trials (e.g., Darwin Lake Project)

Rick Lanoville's Infallible Rule of Thumb for Extreme Fire Behavior: FWI > FFMC



KEETCH-BYRAM DROUGHT INDEX REVISITED: PRESCRIBED FIRE APPLICATIONS



Mike Melton

n volume 50, number 4, of Fire Management Notes, I contributed an article about the Keetch-Byram Drought Index (K-BDI), its relationship to fire suppression. and the problems that could be expected with suppression efforts at different levels of drought as measured by the index. Since that time, it has received many inquiries and comments appreciative of the practical information contained in the article. It has also been used as a training tool in a variety of fire management classes. I also learned that some wildland fire managers, especially in the Southeastern United States, have used the information found in the original article and applied it to prescribed burning. While the information contained in the original article is applicable to prescribed fire, there are some differences. With prescribed fire practitioners in mind, in this article I have expanded and addressed the K-BDI specifically from a prescribed fire perspective.

Keetch-Byram Drought Index (K-BDI) levels are calculated as part of the 1988 revisions of the National Fire-Danger Rating System (NFDRS) (Burgan 1988). Since the K-BDI calculations are simple, they are often made and kept by individuals or field offices that do not have access to NFDRS calculations or are not near an office that does.

Mike Melton is a district ranger, USDA Forest Service, Daniel Boone National Forest, Stearns Ranger District, Whitley Citu. KY. Drought indexes are not designed to measure fuel moistures, rather they indicate environmental conditions that affect fuel profiles.

To calculate the K-BDI values, users need a copy of the directions found in the original documentation (Keetch and Byram 1968) and a rain gauge. Then a simple mathematical process is necessary to determine the K-BDI value on a daily hasis

In the following discussions, I have addressed the index and effects on a drought scale difference of 200, which corresponds to the loss of 2 inches (5 cm) of water from the fuel and soil profile as the drought progresses from one stage to the next.

These following discussions are based on the fact that the seasonal variations in the index generally follow the southern seasonal temperature pattern. The index will be low in the winter and spring, increase during the summer and early fall, and taper off again in winter. In my conclusion, I discuss some of the variations found when the index departs from normal, some things to be expected from rising and falling indexes, and the days-since-rain concept.

K-BDI Levels 0-200

Much of the understory prescribed fire work in the South is done at the 0 to 200 levels, which correspond to the early spring dormant season conditions following winter rains. Soil moisture levels are high, and fuel moistures in the 100- and 1,000-hour fuel classes are sufficiently high, so these larger fuel classes do not significantly contribute to prescribed fire intensity in most cases.

Fuel moistures in the 1- and 10hour classes will vary daily with environmental conditions. On any particular day, prescribed fires should be planned based on the predicted levels of moisture within these two fuel classes in association with weather conditions. Prescribed fire planners should be aware that areas with heavy loadings of these two smaller fuel classes can exhibit intense behavior resulting from the amount of fuel to be consumed. Also, areas that are influenced by slope and aspect can experience erratic and intense fire behavior from the preheating effects. Southern aspects can produce intense fire behavior while northern aspects of the same unit may have difficulty carrying the fire.

At the 0 to 200 levels, nearly all soil organic matter, duff, and the associated lower litter layers are left intact. These layers, even though they may not be soaking

Continued on page 8

The Keetch/Byram Drought Index: A Guide to Fire Conditions and Suppression Problems



Mike Melton

District ranger, USDA Forest Service, Daniel Boone National Forest, Stearns Ranger District, Whitley City, KY

The 1988 version of the National Fire Danger Rating System (NFDRS) has been completed and should be operational by the first part of 1991. The NFDRS has an important new addition: The Keetch/Byram (K/B) Drought Index calculations have been added to the system. As a part of the NFDRS, the K/B index will be the most widely used drought index for fire danger rating. Fire personnel will need to know specifically the effect of drought on both wildfire and prescribed fire and the significance of the index and its relationship to the fire environment. This means fire managers must understand the K/B index system, be able to interpret the data from the system, and apply that knowledge to the local fire situation.

The K/B Index

John Keetch and George Byram developed the K/B index at the Southern Forest Fire Laboratory to evaluate the effects of long-term drying on litter and duff and subsequently, on fire activity (1968). The index is based on a measurement of 8 inches (0.2 m), of available moisture in the upper soil layers that can be used by vegetation for evapotranspiration. The index measure is in hundredths (0.01) of an inch of water and has a range of 0 through 800, with 0 being saturated and 800 representing the worst drought condition. The index indicates deficit inches of available water in the soil. A K/B reading of 250 means there is a deficit of 2.5 inches (6.4 cm) of ground water available to the vegetation. As drought progresses, there is more available fuel that can contribute to fire intensity.

Fire Behavior at Selected K/B Levels

The following information is a compilation of data and observations fire managers and I have made from field observations of both wild and prescribed fire at numerous locations. It is an attempt to qualify and quantify in common terms the effect of continued drought on forest fuels and the problems arising from drought conditions during the course of wildfire and prescribed burns. This information should help fire practitioners to more fully understand the relationship between the K/B index readings-which indicate the extent of drought-and the fire environment.

As a part of the NFDRS, the K/B index will be the most widely used drought index for fire danger rating.

The effect of drought on fire behavior will vary between fuel types and topographic regions. Mountainous hardwood fuels will react differently than the Southern pine fuels to drought and consequently fire effects will also differ. Rain or relative humidity and wind may also require an adjustment to K/B level interpretation. For instance, even if the K/B level is extremely high, a brief rain will temporarily render fuels incapable of burning. Yet on the other hand, the K/B index can be low (<100) and high wind and low relative humidities can create an extreme situation in some fuel types. The following descriptions of conditions at various K/B levels is primarily related to the Southern Coastal Plain and Piedmont regions, but these can be considered applicable in many areas of the country. Fire personnel should remember that specific situations may be different than those described and should use this information to complement his or her experiences at a particular location

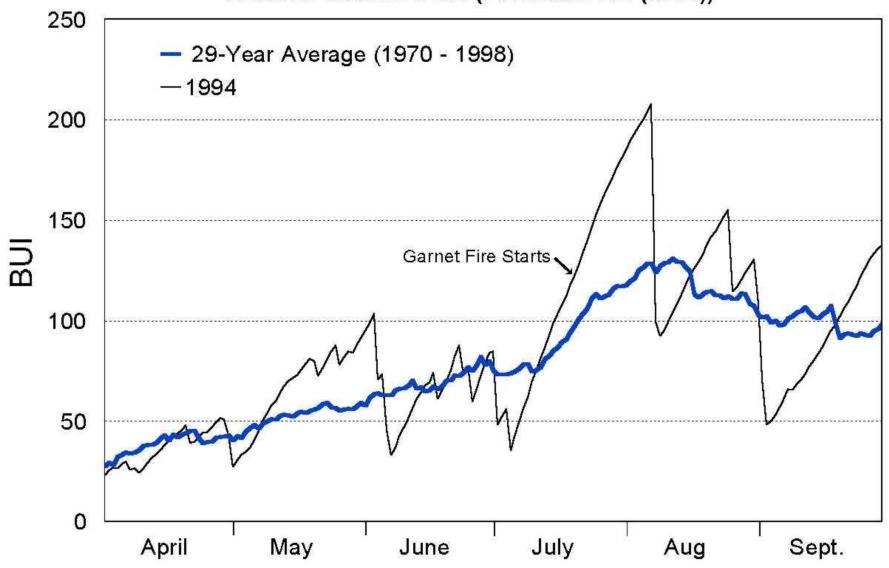
K/B Levels 0-150. During this stage of drought, the fuels and ground are quite moist. Fine fuels exhibit daily drying, burning readily at times but also recovering to a high moisture content at night. This level is ideal for winter or spring prescribed burns. Most fires are easily suppressed with normal practices and generally are not a problem. The lower litter and humus layers are moist and not affected by fire. Most fires die out at night due to humidity recovery and its dampening effect on the fine fuels. Some fuel types (grasses) burn actively, but seldom create much problem with control efforts. Generally, extensive mop-up is not required, since most heavy fuels (100 and 1000 h) are too wet to ignite. Ignition of snags is not normally a problem on wild or prescribed fires. The spring fire season can still generate some extremes in behavior on wildfires due to the nature of fine fuels, especially in fuel types with a heavy loading of grasses. Drying is generally limited to the fine surface fuels and the organic layers still retain sufficient moisture to resist burning. This could be considered the business-as-usual period.

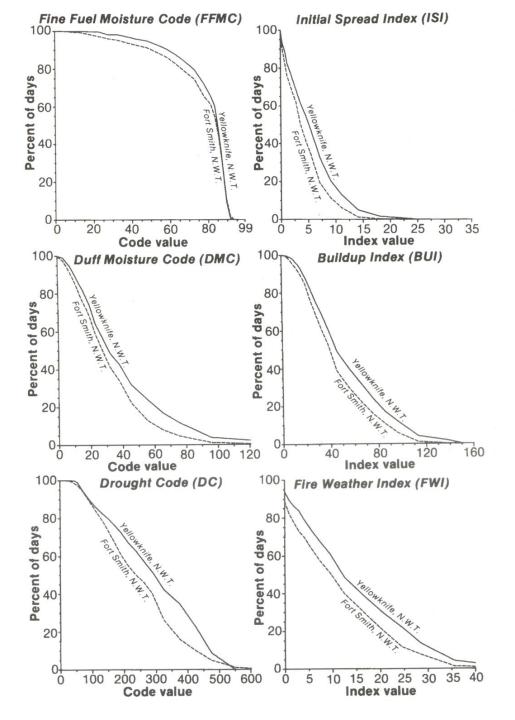
K/B Levels 150-300. Within this range, scattered patches of surface

-

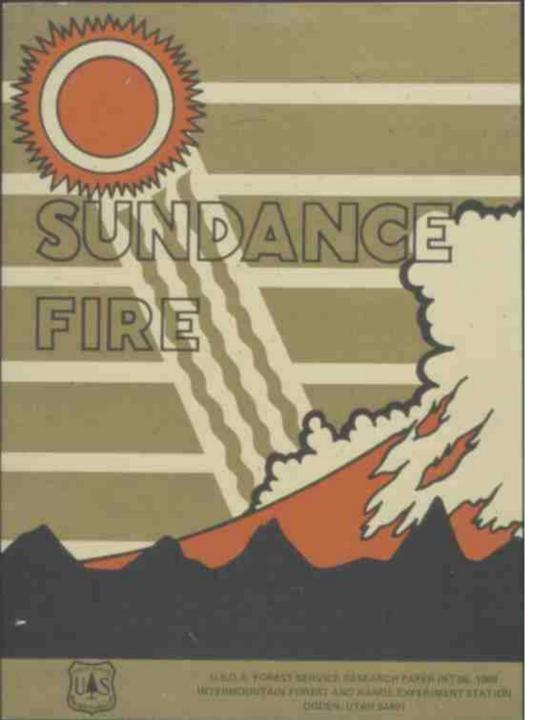
Volume 56 • No. 4 • 1996

Seasonal display chart for the Buildup Index (BUI) at the Ministry of Forests Fire Weather Station 2102 (Penticton RS (NEC))



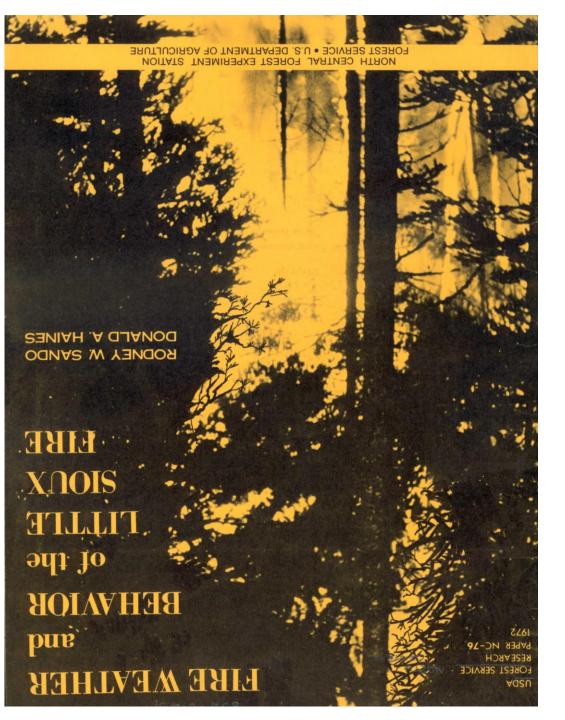


Cumulative frequency distribution curves of the FWI system components for two locations adjacent to the Caribou Range, **Northwest Territories**, based on the 10-year period from 1971 to 1980.



Sundance Fire, Idaho, September 1, 1967

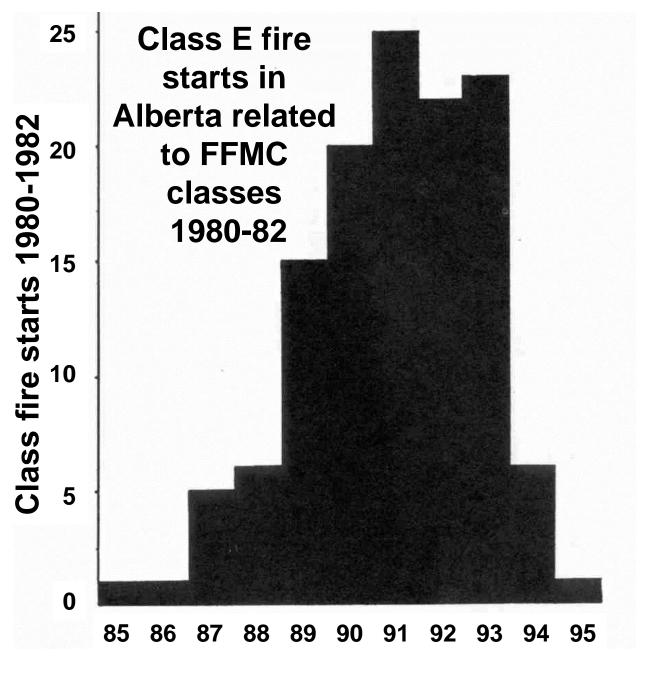
> FFMC 96 DMC 318 DC 752 ISI 24 BUI 318 FWI 68



Little Sioux Fire, Minnesota, May 16 1971

FFMC 95 DMC 45 DC 93 ISI 40 BUI 45 FWI 53

Randall?



The FFMC is a good index of fire starting potential. It is a particularly good indicator of humancaused ignition probability.

FFMC

Prescribed Fire in Spruce-Fir Slash, Maine - June 11, 1965*





III. Fire Behavior Prediction Module or Subsystem

In contrast to the FWI System, the FBP System provides provides quantitative outputs of selected fire behavior characteristics for several major Canadian fuel types and topographic situations.









Development and Structure of the Canadian Forest Fire Behavior Prediction System

> Forestry Canada Fire Danger Group Information Report ST-X-3

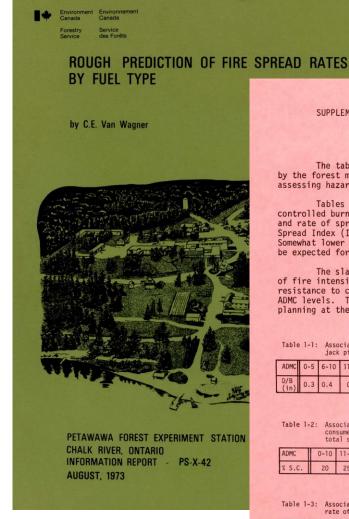


Publication on the Technical Derivation of the FBP System



FBP System is comprises of 89 equations

FBP System Pre-History



SUPPLEMENT ONT-1 TO THE CANADIAN FOREST FIRE BEHAVIOR SYSTEM

A BURNING INDEX FOR JACK PINE LOGGING SLASH

The tables and chart that constitute this index are designed for use by the forest manager (a) in specific prescribed burn planning or (b) in assessing hazard buildup in this fuel type for general p

Tables 1-1, 1-2, and 1-3 will assist fire controcontrolled burns in jack pine slash in estimating duff a and rate of spread in terms of Adjusted Duff Moisture Co Spread Index (ISI) values calculated for 1300 hours on t Somewhat lower fuel consumption and rate of spread figur be expected for morning or evening fires.

The slash hazard chart shown on the following pa of fire intensity (a multiple of rate of spread and fuel resistance to control expected in jack pine slash fires ADMC levels. This chart is designed for broad scale res planning at the division or district level.

Table 1-1: Association between Adjusted Duff Moisture Code (ADMC) and th jack pine slash organic matter (in inches).

| ADMC | 0-5 | 6-10 | 11-16 | 17-21 | 22-26 | 27-32 | 33-37 | 38-42 | 43-56 | 57-66 |
|-------------|-----|------|-------|-------|-------|-------|-------|-------|-------|-------|
| D/B (in) | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 | 1.2 | 1.4 |

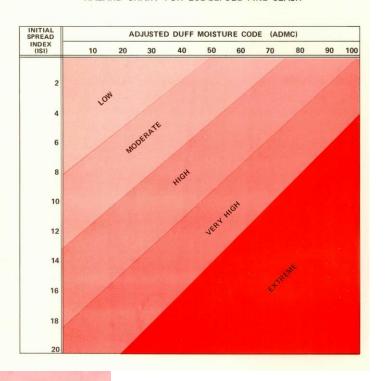
Table 1-2: Association between Adjusted Duff Moisture Code (ADMC) and th consumed (% S.C.), i.e., the amount of slash consumed express total slash available before burning.

| ADMC | 0-10 | 11-19 | 20-26 | 27-35 | 36-43 | 44-51 | 52-59 | 60-67 | 68-75 | 7 |
|--------|------|-------|-------|-------|-------|-------|-------|-------|-------|---|
| % S.C. | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | |

Table 1-3: Association between the Initial Spread Index (ISI) and the ex rate of spread (R/S) of a jack pine slash fire (in feet/minut

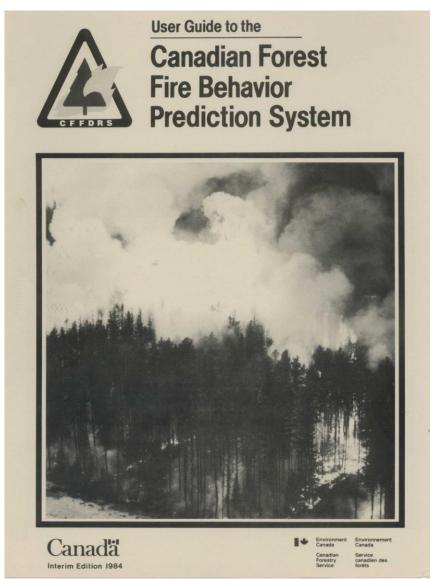
| | ISI | 0 | 1 | 2 | 3 | 4 | 5-6 | 7-8 | 9-10 | 11-12 | 13-14 | 15-16 | 17-18 |
|---|-----------------|---|---|---|----|----|-----|-----|------|-------|-------|-------|-------|
| | R/S (ft/min) | 0 | 4 | 9 | 13 | 17 | 24 | 33 | 42 | 50 | 59 | 68 | 77 |
| - | R/S (ch/hr) | 0 | 4 | 8 | 12 | 15 | 22 | 30 | 38 | 46 | 54 | 62 | 70 |

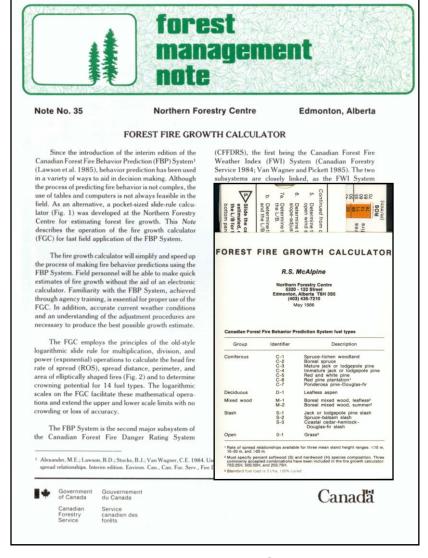
HAZARD CHART FOR LODGEPOLE PINE SLASH



Through 1970's - Regional Burning "Indexes"

FBP System History



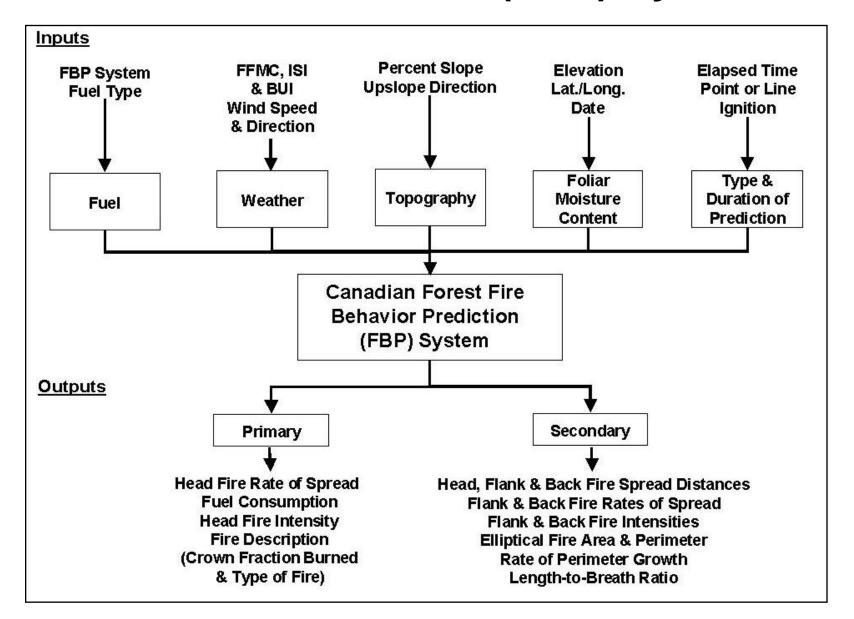


1984 - Interim Edition Released

1986 - Fire Growth Calculator

1992 - 1st Complete Edition Released

Structure of the Canadian Forest Fire Behavior Prediction (FBP) System



FBP System Fuel Types

Canaral

Open

| Category | Fuel Type | Input Modifier |
|------------|--|------------------------|
| | C-1 Spruce-Lichen Woodland | - |
| | C-2 Boreal Spruce | - |
| 0 '' | C-3 Mature Jack or Lodgepole Pine | - |
| Coniferous | C-4 Immature Jack or Lodgepole Pine | - |
| | C-5 Red and White Pine | - |
| | C-6 Conifer Plantation | Live Crown Base Height |
| | C-7 Ponderosa Pine/Douglas-fir | - |
| Deciduous | D-1 Leafless Aspen | - |
| | M-1 Boreal Mixedwood-Leafless | % Softwood/Hardwood |
| Mixedwood | M-2 Boreal Mixedwood-Green | % Softwood/Hardwood |
| mixedwood | M-3 Dead Balsam Fir/Mixedwood-Leafless | % Dead Fir |
| | M-4 Dead Balsam Fir/Mixedwood-Green | % Dead Fir |
| | S 1 Jack or Lodgopolo Bino Slach | _ |
| Slook | S-1 Jack or Lodgepole Pine Slash S-2 Spruce/Balsam Slash | - - |
| Slash | S-3 Coastal Cedar/Hemlock/Douglas-fir Slash | _ |
| | 3-3 Coastal Cedal/Hellilock/Douglas-III Slasii | _ |

O-1a Matted Grass

O-1b Standing Grass

% Degree of Curing

% Degree of Curing

FBP System Fuel Type Characteristics

| Fuel Type | Max. Surface Fuel | Crown Base | Crown Fuel |
|-------------------------------------|--------------------|-------------------|-------------------|
| r doi Type | Consumption (T/Ac) | Height (ft) | Load (T/Ac) |
| C-1 Spruce-Lichen Woodland | 6.7 | 6.6 | 3.3 |
| C-2 Boreal Spruce | 22.3 | 9.8 | 3.6 |
| C-3 Mature Jack or Lodgepole Pine | 22.3 | 26.2 | 5.1 |
| C-4 Immature Jack or Lodgepole Pine | 22.3 | 13.1 | 5.4 |
| C-5 Red and White Pine | 22.3 | 59.0 | 5.4 |
| C-6 Conifer Plantation | 22.3 | 22.9 | 8.0 |
| C-7 Ponderosa Pine/Douglas-fir | 15.6 | 32.8 | 2.2 |
| D-1 Leafless Aspen | 6.7 | - | - |
| M-1 Boreal Mixedwood-Leafless | 22.3 | 19.6 | 3.6 |
| M-2 Boreal Mixedwood-Green | 22.3 | 19.6 | 3.6 |
| M-3 Dead Balsam Fir/Mixedwood-Leafl | less 22.3 | 19.6 | 3.6 |
| M-4 Dead Balsam Fir/Mixedwood-Gree | n 22.3 | 19.6 | 3.6 |

S-1 Jack or Lodgepole Pine Slash

S-3 Coastal Cedar/Hemlock/Douglas-fir Slash

S-2 Spruce/Balsam Slash

O-1a Matted Grass

O-1b Standing Grass

35.7

71.4

142.7

0.3

0.3

FBP System Fuel Types





Examples of

FUEL TYPES

in the

CANADIAN FOREST
FIRE BEHAVIOR
PREDICTION (FBP) SYSTEM



Forestry Forets Canada Canada





FBP System Fuel Type C-2 (Boreal Spruce)

This fuel type is characterized by pure, moderately wellstocked black spruce stands on lowland (excluding Sphagnum bogs) and upland sites. Tree crowns extend to or near the ground and dead branches are typically draped with bearded lichens (Usnea sp.). The flaky nature of the bark on the lower portion of stem boles is pronounced. Low to moderate volumes of down woody material are present. Labrador tea (Ledum Groenlandicum Oeder) is often the major shrub component. The forest floor is dominated by a carpet of feather mosses and/or ground-dwelling lichens (chiefly Clodonia). Sphagnum mosses may occasionally be present, but they are of little hindrance to surface fire spread. A compact organic layer commonly exceeds a depth of 23-30 cm (9 - 12 in.).

Inputs and **Outputs** of the **FWI System** used in the FBP **System**



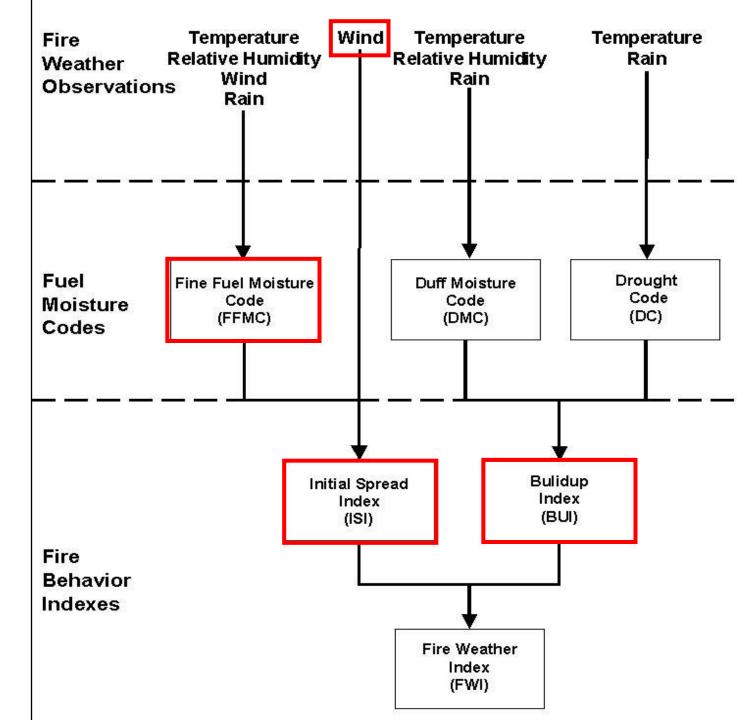
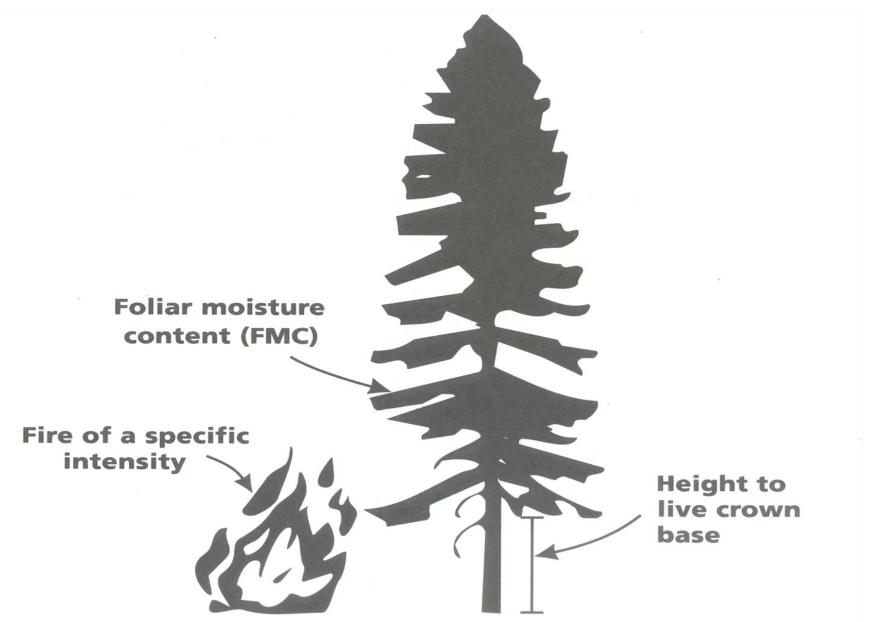
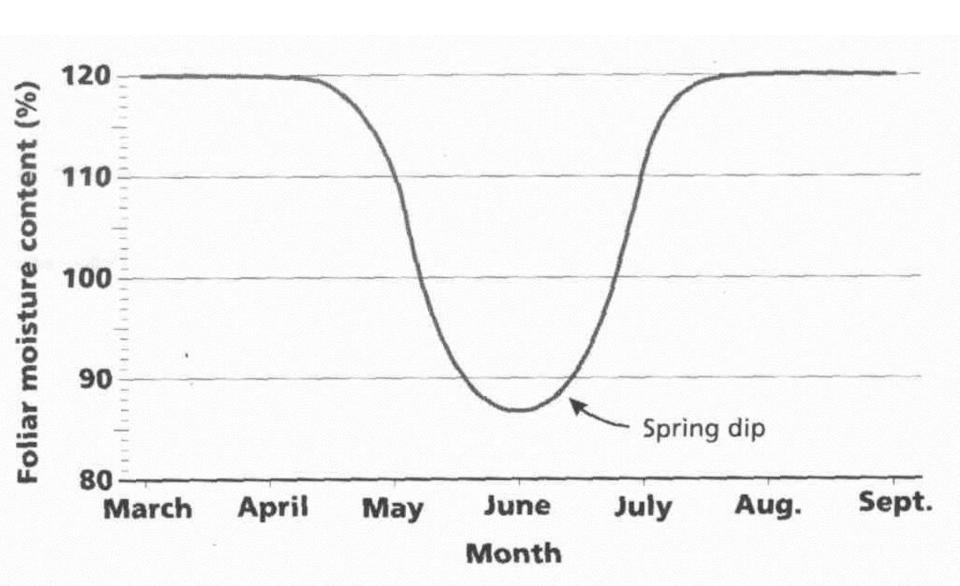


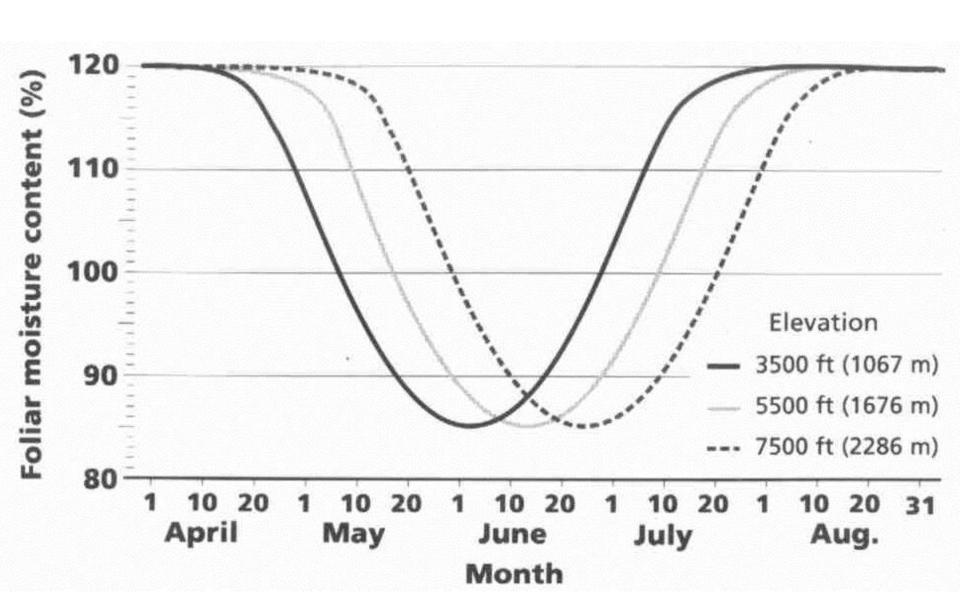
Illustration of the parameters influencing the prediction of crown fire initiation

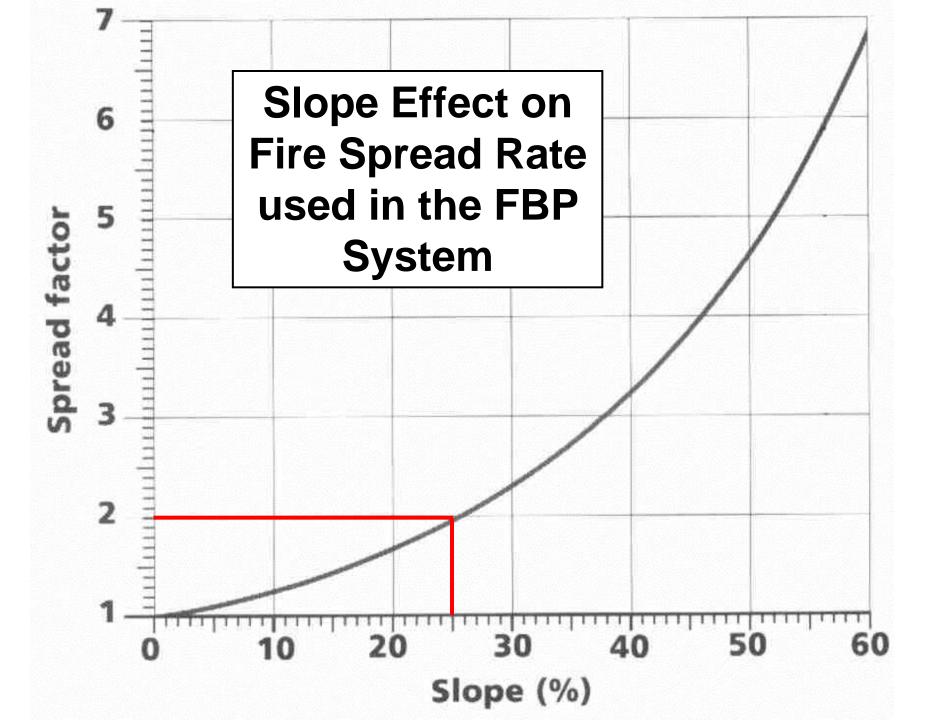


Conceptual example of the seasonal trend in the foliar moisture content of conifer foliage

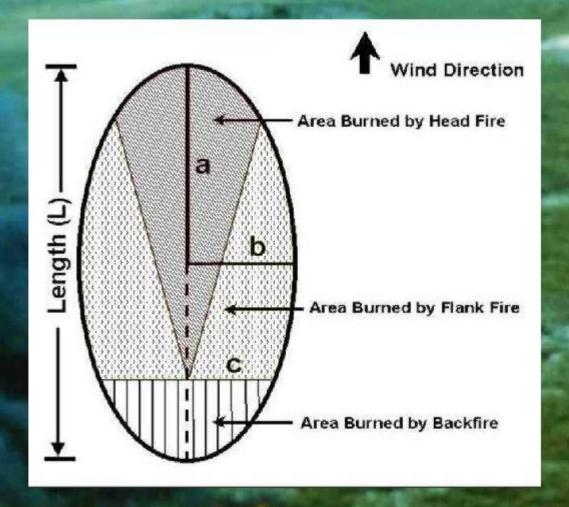


An example of foliar moisture content calculated by the FBP System for west-central Alberta

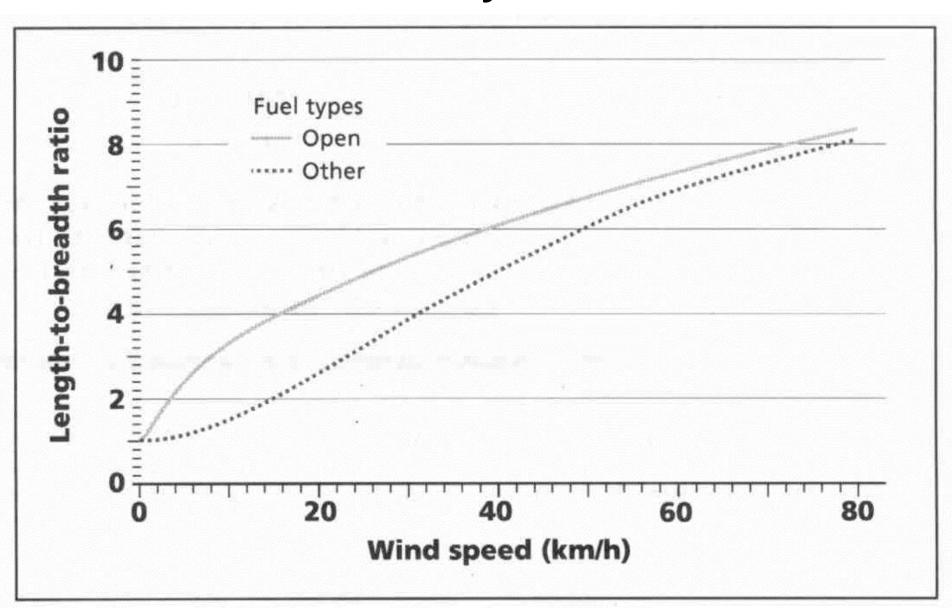




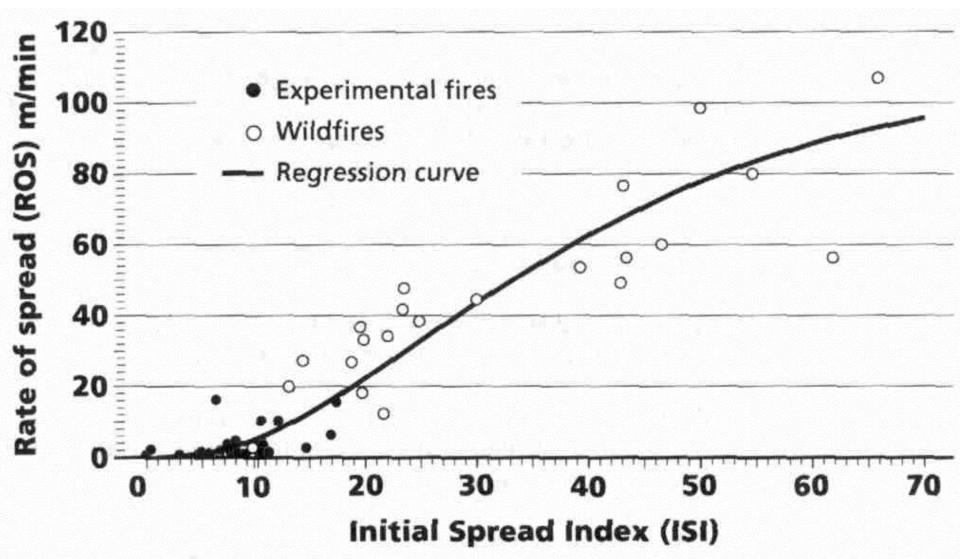
A Simple **Elliptical** Fire Growth Model is **Employed** in the FBP System



Length-to-breadth ratio curves used in the FBP System

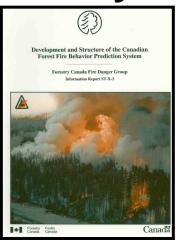


Basic rate of spread curve for FBP System
Fuel Type C-3
(Mature Jack or Lodgepole Pine)



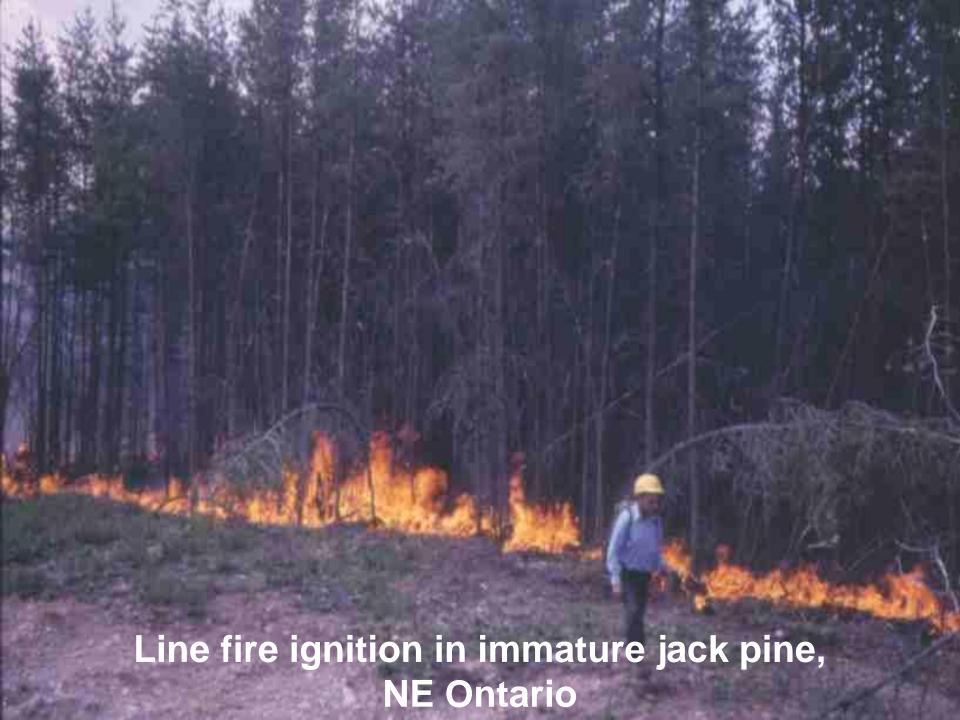


Creating the basic FBP System database

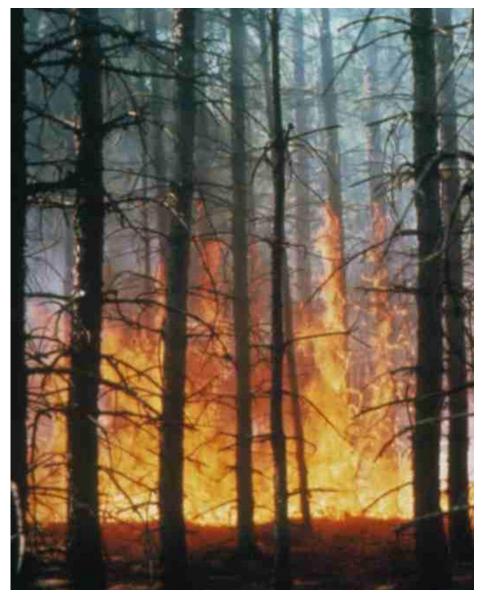


See video:
"Mounting the
Attack on
Wildfire"











Experimental fire in red pine plantation, Petawawa, Ontario



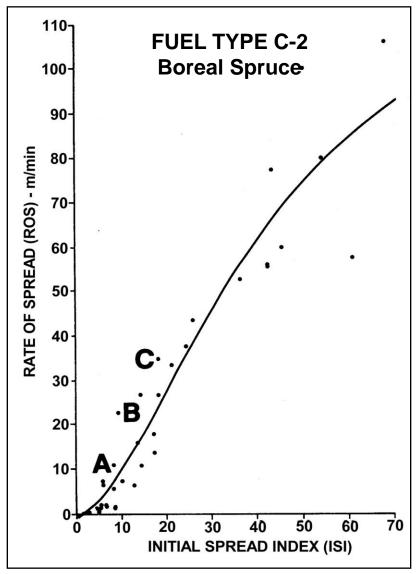






Case Study: 1981 Hay River-36-81 Fire, NWT

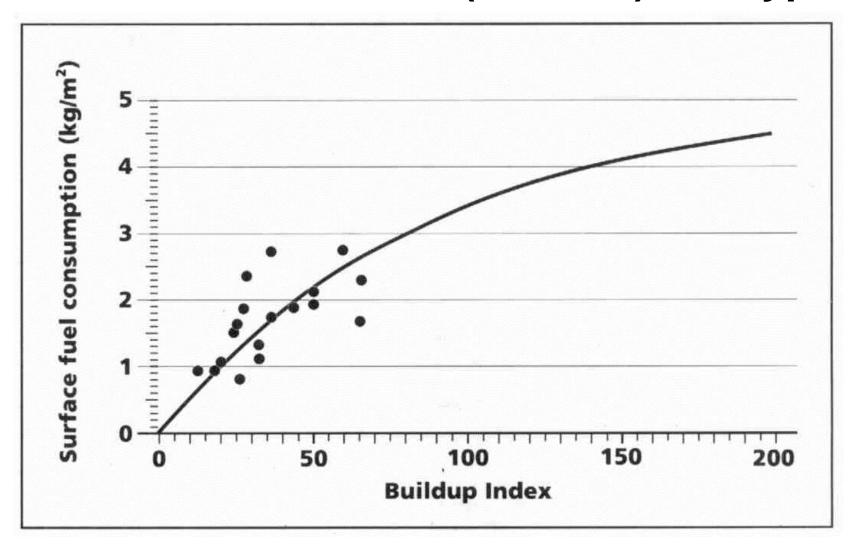
FBP System Rate of Spread (ROS) Component analysis





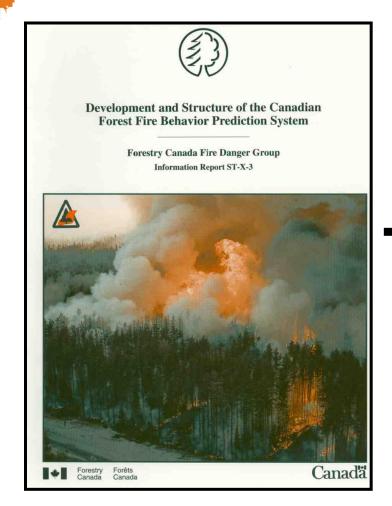
Hay River Fire 36-81 provided 3 data points for model development

Surface fuel consumption curve and data points for the Boreal Spruce (C-2), Dead Balsam Fir/Mixedwood (M-3/M-4) fuel types.





"Operationalizing" the FBP System



FIELD GUIDE TO THE CANADIAN FOREST FIRE BEHAVIOR PREDICTION (FBP) SYSTEM S.W. Taylor R.G. Pike and M.E. Alexander Canadä

Technical & Scientific Documentation

Operational Field Manual (FBP System "Red Book")





Flow chart of procedures used in the guide

Fire no., prediction interval, ignition type

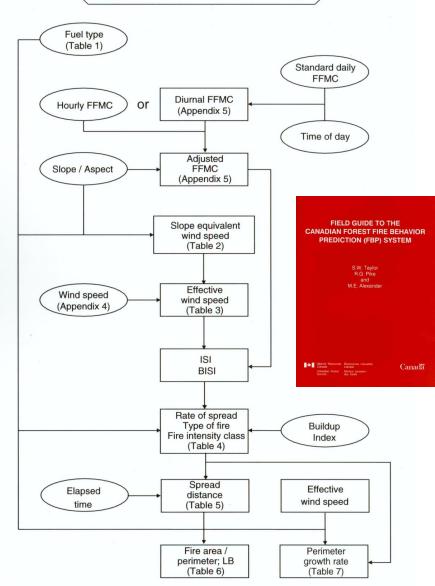


Table 4.1 Equilibrium rate of spread (m/min) and fire intensity class

C-1 spruce-lichen woodland

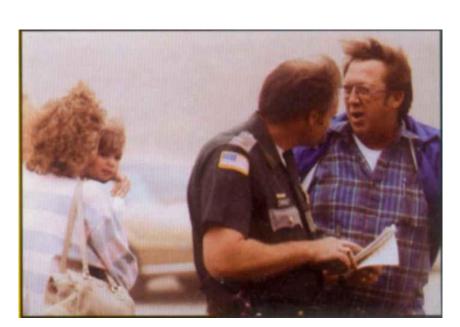


| | | | | BU | II | | | |
|-------|-----|-------|-------|-------|---------|-------|-------|-------|
| 101 | 0- | 21- | 31- | 41- | 61- | 81- | 121- | 161- |
| ISI | 20 | 30 | 40 | 60 | 80 | 120 | 160 | 200 |
| 1 | 0 | 0 | 0 | 0 | 0 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 |
| 4 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 5 | 0.2 | 0.2 | 0.3 | 0.3 | 2 0.3 | 0.3 | 0.3 | 0.3 |
| 6 | 0.4 | 0.5 | 0.5 | 0.5 | 0.6 | 0.6 | 0.6 | 0.6 |
| 7 | 0.6 | 0.8 | 0.9 | 0.9 | 1 | 1 | 1 | 1 |
| 8 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| 9 | 1 | 2* | 2* | 2* | 3 2* | 2* | 2* | 2* |
| 10 | 2* | 3* | 3* | 3* | 3* | 3* | 3* | 3* |
| 11 | 3* | 4* | 4* | 4* | 4 4* | 4* | 5* | 5* |
| 12 | 4* | 5* | 5* | 5* | 6* | 6* | 6* | 6* |
| 13 | 5* | 6* | 7* | 7* | 7* | 7* | 7* | 7* |
| 14 | 6* | 8* | 8* | 9* | 9* | 9* | 9* | 9* |
| 15 | 7* | 9* | 10* | 10* | (5) 11* | 11* | 11* | 11* |
| 16 | 8* | 11* | 12 | 12 | 13 | 13 | 13 | 13 |
| 17 | 9* | 13 | 14 | 14 | 15 | 15 | 15 | 15 |
| 18 | 11* | 15 | 16 | 16 | 17 | 17 | 17 | 18 |
| 19 | 12 | 17 | 18 | 19 | 19 | 20 | 20 | 20 |
| 20 | 14 | 19 | 20 | 21 | 21 | 22 | 22 | 22 |
| 21–25 | 18 | 25 | 27 | 28 | 29 | 29 | 30 | 30 |
| 26–30 | 26 | 35 | 38 | 39 | 40 | 41 | 42 | 42 |
| 31–35 | 33 | 45 | 48 | 50 | 51 | 52 | 53 | 54 |
| 36–40 | 39 | 53 | 56 | 59 | 6 60 | 62 | 63 | 63 |
| 41–45 | 44 | 59 | 63 | 66 | 68 | 69 | 70 | 71 |
| 46–50 | 50 | 64 | 68 | 71 | 73 | 75 | 76 | 77 |
| 51–55 | 51 | 68 | 72 | 75 | 78 | 79 | 81 | 81 |
| 56–60 | 52 | 71 | 75 | 78 | 81 | 83 | 84 | 85 |
| 61–65 | 54 | 73 | 77 | 81 | 83 | 85 | 86 | 87 |
| 66–70 | 55 | 75 | 79 | 83 | 85 | 87 | 88 | 89 |

"Red Book" Exercise - The Scenario:

- a fire is reported 5 km from a community
- winds are currently and are also forecasted to blow directly towards the town at 15 km/h
- fire danger conditions: FFMC 92, BUI 90
- fuels and topography: area dominated by black spruce forests on level terrain

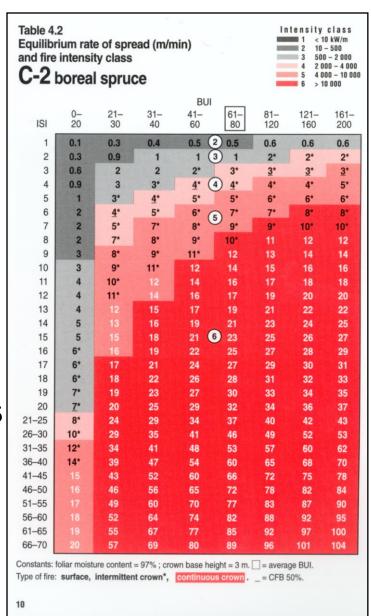
Question:
What would you
tell the local
community
leaders?



"Red Book" Exercise - The Schoolbook Solution

Computations:

- determine ISI value: 12
- determine Head Fire Intensity Class: 6 (> 10 000 kW/m)
- determine equilibrium head fire ROS: 17 m/min or ~ 1 km/h (m/min x 0.06 = km/h)
- determine time for fire to reach community:
 - (Distance \bigcirc ROS): $5\bigcirc 1 = 5$ hours
- determine L/B: 2.0
- determine fire breadth or maximum width



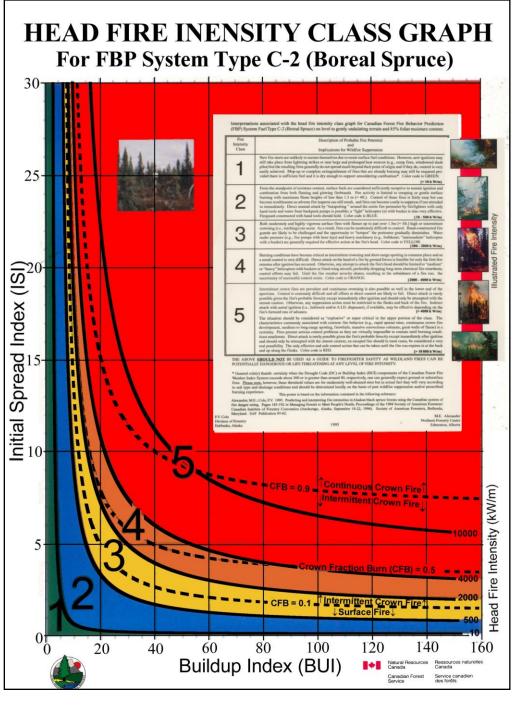


"Red Book" Exercise - The Schoolbook Solution

The Important Take Home Message:

KEEP IT SIMPLE & RELEVANT FOR THE PARTICULAR AUDIENCE

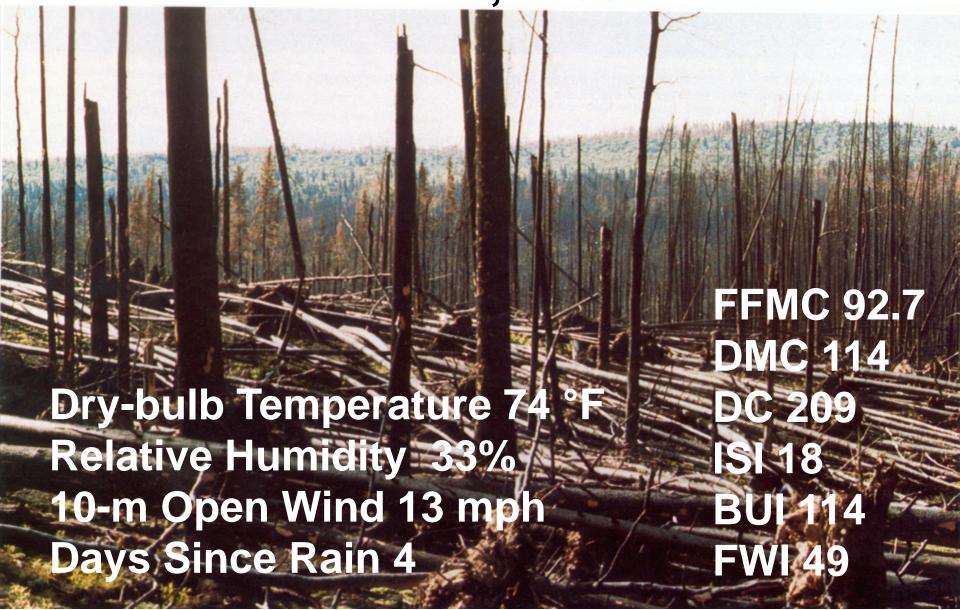


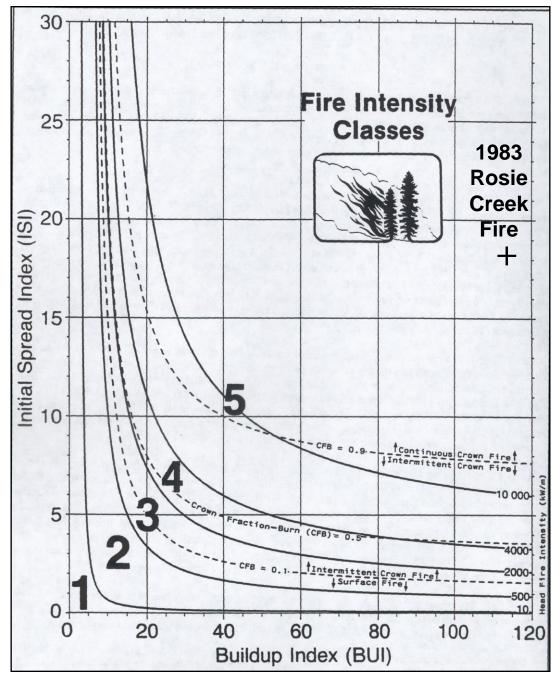


Cole & Alexander (1995) wall poster

Alexander & Cole (1995) technical paper presented at the SAF/CIF **Joint National** Convention, Anchorage, Alaska, Sept. 18-22, 1994

Rosie Creek Fire near Fairbanks, Alaska
June 2, 1983







Rosie Creek Fire near Fairbanks, Alaska June 2, 1983

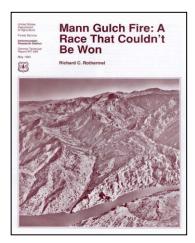


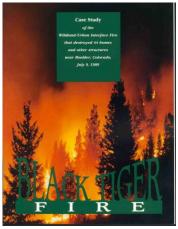
Description of Probable Fire Potential and Implications for Wildfire Suppression at Head Fire Intensity Class 5*

The situation should be considered as "explosive" or super critical in the upper portion of the class. The characteristics commonly associated with extreme fire behavior (e.g., rapid spread rates, continuous crown fire development, medium- to long-range spotting, firewhirls, massive convection columns, great walls of flame) is a certainty. Fires present serious control problems as they are virtually impossible to contain until burning conditions ameliorate. Direct attack is rarely possible given the fire's probable ferocity except immediately after ignition and should only be attempted with the utmost caution; an escaped fire should in most cases, be considered a very real possibility. The only effective and safe control action that can be taken the fire run expires is at the back and up along the flanks. *from Alexander and Cole (1995)

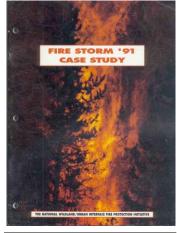


IV. Selected Wildfire Case Studies













THE OLD FATHFUL PIRE RIJN OF SEPTEMBER 7, 1989:

DA THOMAS:

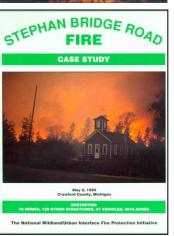
DA THOMAS:

ABSTRACT: This paper discusses the fire is behavior of the cower fire that burned onto the Os Faithful Gener complex in Yestown Motional Plant, Wyorning, on September 7, 1989. The fire years of the county of the plant of the county of the plant of the county of the plant of the plan

¹A paper presented at the 11th Conference on Fire and Forest Meteorology, April 16-19, 1991, at Missoula, MT.

*David A. Thomas, Fire Management Officer, U.S. Forest Service, Lolo National Forest, Box 460, Superior Ranger District, Superior, MT 59872.

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Wildfire Case Studies: Major Impacts

| Name of Wildfire or Incident | Total Area Burned (ad | | Major Injuries |
|--|---|--|------------------------------|
| Mann Gulch Mack Lake Butte Fire Old Faithful Complex Black Tiger Stephan Bridge Road NE Wash. Firestorm '91 Oakland/Berkeley Hills | 5000 23 831 unknown 27 777 2100 5916 35 000** 1532 | 13 Firefighters 1 Firefighter None* None None 1 Civilian 23 Civilians 1 Firefighter 1 Police Officer | None None* None 1 1 None 150 |

^{*73} Firefighters deployed fire shelters

^{**}Based on 92 separate ignitions

Wildfire Case Studies: Major Impacts

| Name | of | Wildfire |
|------|-----|----------|
| or | Inc | ident |

Mann Gulch

Description of Structural Losses

| Mack Lake | 44 Homes & cottages destroyed |
|------------|-------------------------------|
| Butte Fire | None |

None

| Old Faithful Complex | 14 Cabins & 10 other buildings destroyed |
|----------------------|--|
| | |

| Black Tiger | 44 Homes & other buildings destroyed and |
|-------------|--|
| | many others damaged |

| Stephan Bridge Road | 76 Homes & 125 other buildings destroyed |
|---------------------|--|
| | |

| NE Wash. Firestorm '91 | 114 Homes & other buildings destroyed |
|------------------------|---------------------------------------|
|------------------------|---------------------------------------|

| Oakland/Berkeley Hills | 2449 Homes and 437 apartment & |
|------------------------|--------------------------------|
| | condominuim units destroyed |

Mann Gulch Fire, Western Montana August 5, 1949 **FFMC 95.5 DMC 141 Dry-bulb Temperature 91 °F** DC 436 **Relative Humidity 24% ISI 42.2** 10-m Open Wind 18.6 mph **BUI 156 Days Since Rain 8 FWI 90**

Mann Gulch Fire, Western Montana August 5, 1949

The following hindsight predictions of selected fire behavior characteristics using the FBP System are based on a 18% Slope, 120% Foliar Moisture Content and 100% Degree of Curing at 15 minutes Elapsed Time "T" Since Ignition for a Point Source Fire based on the FWI System components prevailing at 12:00 p.m. MST:

FBP System Fuel Type C-7 (Ponderosa Pine - Douglas-fir)
Head Fire Rate of Spread: 82 ft/min
Head Fire Intensity: 8239 Btu/sec-ft

Forward Spread Distance (5:45-6:00 p.m. MST): 1230 ft*

FBP System Fuel Type: O-1b (Standing Grass; 3.0 t/ha fuel load)

Head Fire Rate of Spread: 646 ft/min

Head Fire Intensity: 5117 Btu/sec-ft

Forward Spread Distance: 9695 ft*

*For comparison sake, the fire was estimated to have advanced 1115-1160 m during the 15-minute interval from 5:45-6:00 p.m. MST. For the FBP System predictions to match this, the portion of montane forest cover (Fuel Type C-7) to grasslands (Fuel Type O-1b) would have had to be ~60:40 which is not unrealistic based on the available photographic evidence.

Mack Lake Fire, Michigan May 5, 1980

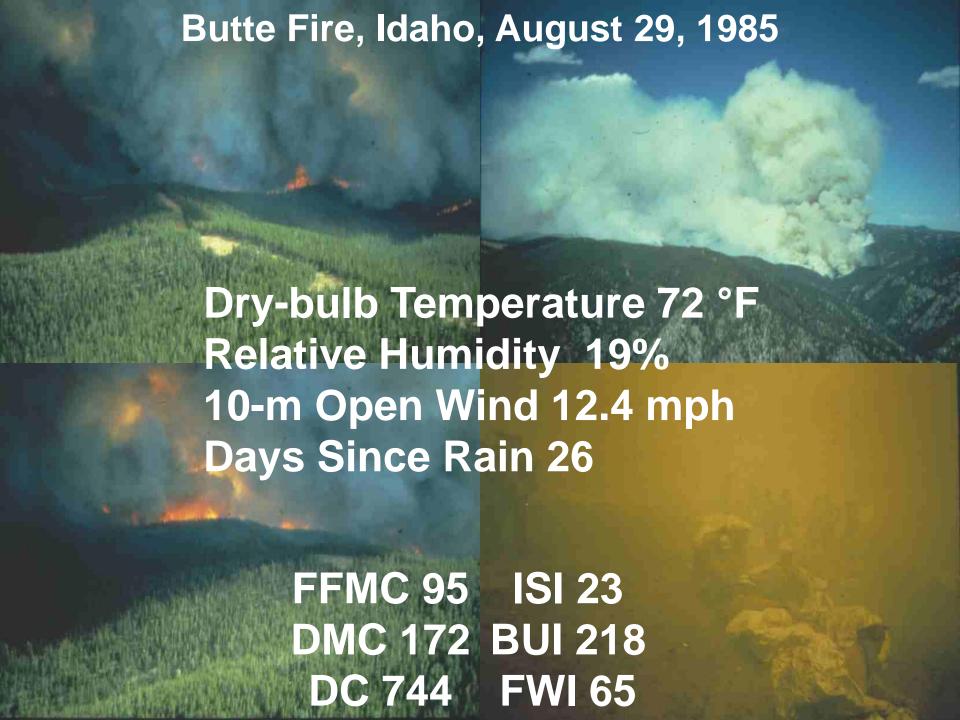
Dry-bulb Temperature 80 °F Relative Humidity 24% 10-m Open Wind 20.5 mph Days Since Rain 6 FFMC 94.6 DMC 35 DC 59 ISI 43.2 BUI 35 FWI 50

Mack Lake Fire, Michigan May 5, 1980

The following comparisons are based on the major run of the Mack Lake Fire that occurred between 1230 and 1600 hours EDT on May 5, 1980 using FBP System Fuel Type C-4, a 0% Slope and 100% Foliar Moisture Content:

| - | | |
|-----------------------------------|------------------|-----------------|
| Fire Behavior Characteristic | Predicted | Observed |
| Head Fire Rate of Spread (ft/min) | 187 | 184 |
| Head Fire Intensity (Btu/sec-ft) | 9731 | 8890 |
| Forward Spread Distance (mi) | 7.1 | 7.5 |
| Area Burnt (Acres) | 6262 | 6778 |
| Fire Perimeter (mi) | 15.4 | 12.4 |

Predicted Type of Fire at the "Head":
Continuous Crown Fire (100% Crown Fuel Involvement)



Butte Fire, Idaho, August 29, 1985

The following comparisons are based on the major run of the Butte Fire that occurred between 1430 and 1610 hours MDT on August 29, 1985 using FBP System Fuel Type C-3, a 9% slope and 105% Foliar Moisture Content:

| Fire Behavior Characteristic | Predicted | <u>Observed</u> |
|-----------------------------------|------------------|-----------------|
| Head Fire Rate of Spread (ft/min) | 73 | 81 |
| Head Fire Intensity (Btu/sec-ft) | 12,525 | N/A |
| Forward Spread Distance (ft) | 7283 | 8070 |

Predicted Type of Fire at the "Head":

Continuous Crown Fire (>99% Crown Fuel Involvement)

North Fork Fire, Wyoming (Old Faithful Complex) - September 7, 1988

Dry-bulb Temperature 67 °F Relative Humidity 24% 10-m Open Wind 15 mph Days Since Rain 25 FFMC 93.9 DMC 183 DC 787 ISI 25 BUI 232 FWI 70

North Fork Fire, Wyoming (Old Faithful Complex) - September 7, 1988

The following predictions are made in relation to the major run of the North Fork Fire that occurred around 1540 hours MDT in the vicinity of Old Faithful Inn in Yellow National Park on September 7, 1988 using FBP System Fuel Type C-3, a 0% Slope and 120% Foliar Moisture Content:

| Fire Behavior Characteristic | <u>Predicted</u> | <u>Observed</u> |
|-----------------------------------|------------------|-----------------|
| Head Fire Rate of Spread (ft/min) | 128 | N/A |
| Head Fire Intensity (Btu/sec-ft) | 20,026 | N/A |
| Flank Fire Intensity (Btu/sec-ft) | 2948 | N/A |

Predicted Type of Fire:

Continuous Crown at the "Head" (100% Crown Fuel Involvement)

Intermittent Crowning at the Flank (50% Crown Fuel Involvement)

Black Tiger Fire, Colorado July 9, 1989

Dry-bulb Temperature 98 °F Relative Humidity 24% 10-m Open Wind 12 mph Days Since Rain 13

FFMC 95.2 DMC 111 DC 269 ISI 24.5 BUI 111 FWI 59







Black Tiger Fire, Colorado July 9, 1989

The following comparisons are based on the major run of the Black Tiger Fire that occurred between 1235 and 1800 hours MDT on July 9, 1989 using FBP System Fuel Type C-7, a 23% Upslope Projection and 110% Foliar Moisture Content:

| Fire Behavior Characteristic | Predicted | Observed |
|------------------------------------|------------------|-----------------|
| Head Fire Rate of Spread (ft./min) | 19 | 14 |
| Head Fire Intensity (Btu/sec-ft) | 6199 | N/A |
| Forward Spread Distance (mi.) | 3.8 | 2.9 |

Predicted Type of Fire at the "Head":

Continuous Crown Fire (95% Crown Fuel Involvement)

Stephan Bridge Road Fire Michigan May 8, 1990

Dry-bulb Temperature 82 °F Relative Humidity 26% 10-m Open Wind 17.4 mph Days Since Rain 14



FFMC 93.6 DMC 68 DC 112 ISI 29.1 BUI 68 FWI 52

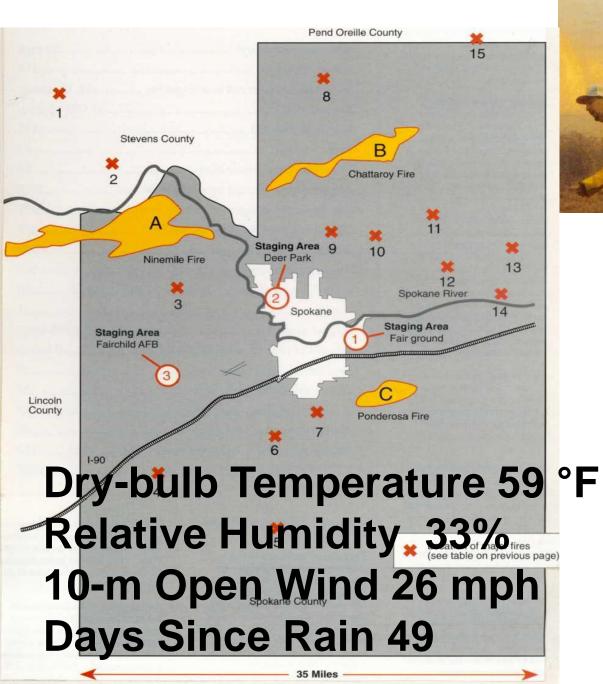
Stephan Bridge Road Fire Michigan May 8, 1990

The following comparisons are based on the major run of the Stephan Bridge Road Fire that occurred between 1540 and 1930 hours EDT on May 8, 1990 using FBP System Fuel Type C-4, a 0% Slope and 100% Foliar Moisture Content:

| - | | |
|------------------------------------|------------------|-----------------|
| Fire Behavior Characteristic | Predicted | <u>Observed</u> |
| Head Fire Rate of Spread (ft./min) | 174 | 184 |
| Head Fire Intensity (Btu/sec-ft) | 14,859 | N/A |
| Forward Spread Distance (mi.) | 7.2 | 8.0 |
| Area Burnt (Acre) | 7129 | 4490 |
| Fire Perimeter (mi) | 15.8 | 15.4 |

Predicted Type of Fire at the "Head":
Continuous Crown Fire (100% Crown Fuel Involvement)

MAJOR FIRES IN AND AROUND SPOKANE



Northeastern
Washington
Fires - October
16,1991

FFMC 92.0 DMC 339 DC 1026 ISI 47.3 BUI 371 FWI 102

Northeastern Washington Fires - October 16, 1991

Unfortunately, insufficient details on fuel types and topographic characteristics are not readily available on individual fires to able any quantitative comparisons to be made. However, the following predictions are on the general burning conditions that prevailed on October 16, 1991 and are certainly indicative if the extreme fire behavior that prevailed. These predictions are based on 0% Slope, 120% Foliar Moisture Content (in the case of FBP System Fuel Type C-7) and 100% Degree of Curing (in

| Fire Benavior Characteristic | <u>ruei Type C-7</u> | <u>ruei Type OT-b</u> |
|------------------------------------|----------------------|-----------------------|
| Head Fire Rate of Spread (ft./min) | 92 | 184 |
| Head Fire Intensity (Btu/sec-ft) | 9120 | 5293.7 |

| the case of FBP System Fuel Type O-1b) | | | |
|--|---------------|----------------|--|
| Fire Behavior Characteristic | Fuel Type C-7 | Fuel Type O1-b | |
| Head Fire Rate of Spread (ft./min) | 92 | 184 | |
| Head Fire Intensity (Btu/sec-ft) | 9120 | 5293.7 | |

Fire Size After 1 Hour Forward Spread Distance (mi.) 6.5 0.9 **Elliptical Fire Area (Acres) 74** 3427

Elliptical Fire Perimeter (mi.) 1.8 13.4

Predicted Type of Fire at the "Head" (Fuel Type C-7): Continuous Crown Fire (99% Crown Fuel Involvement)

Oakland/Berkeley Hills Fire, California October 21, 1991

Dry-bulb Temperature 90 °F Relative Humidity 17% 10-m Open Wind 23 mph Days Since Rain 67

FFMC 95.7 DMC 164 DC 1082 ISI 61.5 BUI 238 FWI 118

Oakland/Berkeley Hills Fire, California October 21, 1991

The following comparisons are based on the major run of the Oakland/Berkeley Hills Fire between 1100 and 1200 hours PDT on October 20, 1991 using FBP System Fuel Type C-7, a 12% Downslope Projection and 120% Foliar Moisture Content:

| Fire Behavior Characteristic | Predicted | <u>Observed</u> |
|-----------------------------------|------------------|-----------------|
| Head Fire Rate of Spread (ft/min) | 98 | 82 |
| Head Fire Intensity (Btu/sec-ft) | 9951 | N/A |
| Forward Spread Distance (mi) | 0.9 | 0.9 |

Predicted Type of Fire at the "Head":

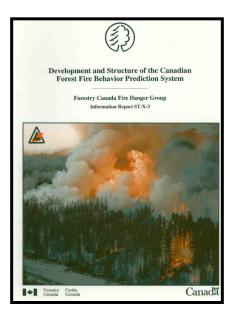
Continuous Crown Fire (100% Crown Fuel Involvement)

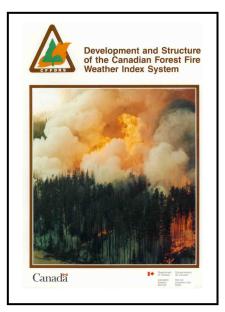


V. Basic Similarities & Differences Between Canadian & U.S. Systems

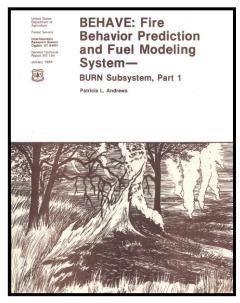
















Fire Environment Inputs: Fuels



- Canadian
 - -16 Fuel Types



- U.S.
 - -13 FireBehavior FuelModels
 - 20 Fire DangerFuel Models
 - Customized Fuel Models



Fire Environment Inputs: Live Fuel Moisture



- Canadian
 - Conifer Foliar MC
 Estimated From
 Calendar Date,
 Location (Lat./Long)
 and Elevation



- U.S.
 - Understory Live
 Moisture Content
 (Herbaceous &
 Woody) Estimates
 Based on Phenology
 Required for Certain
 Fuel Models.





Fire Environment Inputs: Dead Fuel Moisture



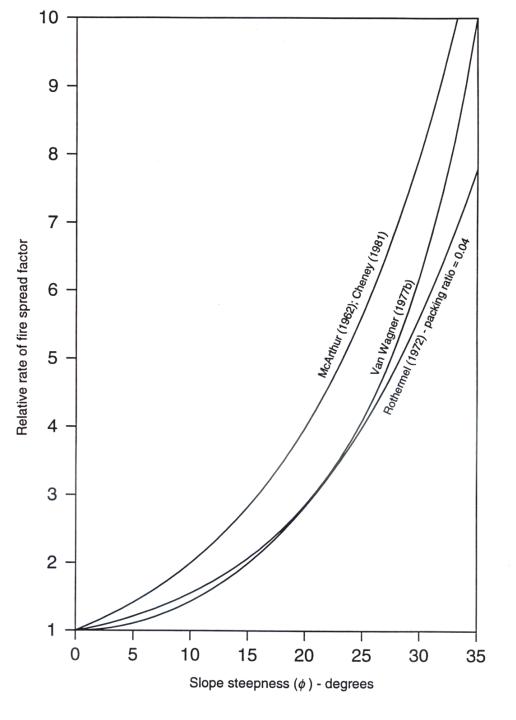
- Canadian
 - FWI System Fuel
 Moisture Codes
 Dependent on the
 Continuity of Daily
 Wx. Readings
 - Emphasis on ForestFloor Layer

- U.S.
 - Dead Fuel Moisture
 Content (1-hr, 10-hr, 100-hr, 1000-hr TL's)
 Calculated From Current
 Wx. Observations Plus
 Other Environmental
 Variables
 - Emphasis on
 Herbaceous & Woody
 Vegetation & Dead Down Roundwood Fuels

Fire Environment Inputs: Topography

- Canadian
 - Considers the
 Mechanical Effects
 of % Slope on Fire
 Behavior
 - Uses a VectoringApproach For Cross-Slope Situations

- U.S.
 - Considers the
 Mechanical Effects
 of % Slope on Fire
 Behavior
 - Uses BasicVectoring for Cross-Slope Situations



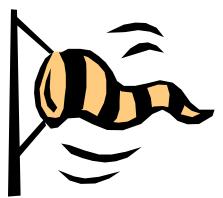
The effect of slope steepness on uphill rate of fire spread of free-burning wildland fires in the absence of wind according to Australian (McArthur 1962; Cheney 1981), Canadian (Van Wagner 1977b) and American (Rothermel 1972) authorities

Fire Environment Inputs: Weather



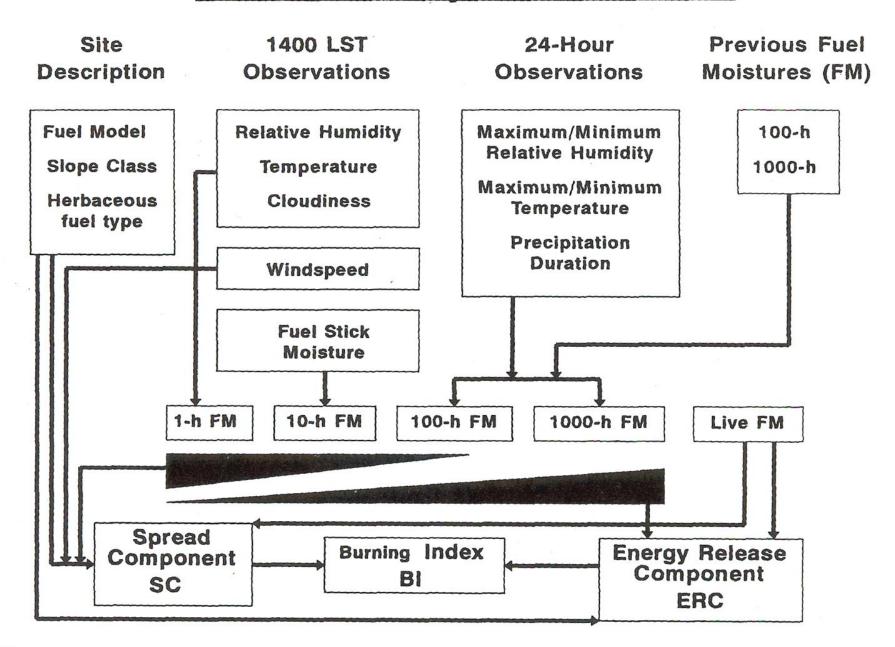


- Canadian
 - Open WindMeasured at 10-mHeight



- U.S.
 - Open WindMeasured at 20-ft(6.1-m) Height
 - Open Wind Adjusted for Vegetative Cover
 & Topographic Position to "Midflame" Wind Speed

U.S. NFDRS System Structure



Fire Danger Index Equivalencies



Canadian

FFMC

DMC/BUI

• DC

· ISI

FWI



U.S.

·IC

• ERC

KBDI

· SC

BI







Environment Canada Environnement Canada

Forestry

Service des Forêts

A CALCULATOR PROGRAM FOR THE CANADIAN FIRE WEATHER INDEX (MAGNETIC CARD VERSION)

Peter H. Kourtz

PETAWAWA NATIONAL FORESTRY INSTITUTE CHALK RIVER, ONTARIO, CANADA KOJ 1J0

INFORMATION REPORT PI-X-3

INSTITUT FORESTIER NATIONAL DE PETAWAWA CHALK RIVER, ONTARIO, CANADA KOJ 1J0

RAPPORT D'INFORMATION PI-X-3
Juillet 1980

FIRE DANGER / FIRE BEHAVIOR COMPUTATIONS WITH THE TEXAS INSTRUMENTS TI-59 CALCULATOR:

USER'S MANUAL

Robert E. Burgan



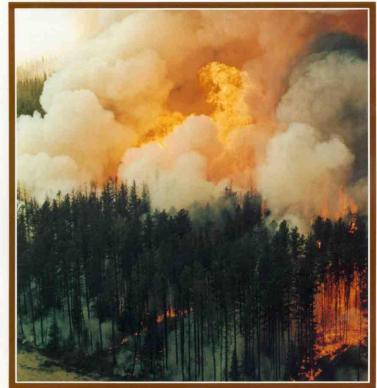
USDA Forest Service General Technical Report INT-61 INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE







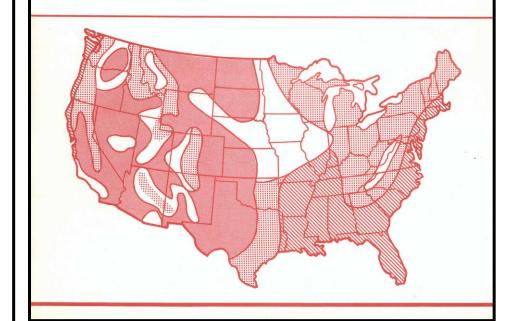
Development and Structure of the Canadian Forest Fire Weather Index System



Canada

United States Department of Agriculture Forest Service Intermountain Forest and Range Experiment Station Ogden, Utah 84401 General Technical Report INT-169

The 1978 National **Fire-Danger Rating** System: Technical Documentation









forest management note

Note No. 43

Northern Forestry Centre

Edmonton, Alberta

TWO BASIC PROGRAMS FOR FIRE DANGER AND FIRE BEHAVIOR COMPUTATIONS

Two computer programs pertaining to the Canadian Forest Fire Danger Rating System (CFFDRS) calculate Canadian Forest Fire Weather Index (FWI) System (Canadian Forestry Service 1984) component values and predict fire behavior using procedures from the Canadian Forest Fire Behavior Prediction (FBP) System (Lawson et al. 1985). The programs were written for a NEC PC-8201A1 lap computer (Fig. 1) but can be adapted to any computer with approximately 24 KB of memory that supports some dialect of the BASIC computer language.

The first program, named LAPFWI (Lap computer Fire Weather Index), is a program to calculate component indexes of the FWI System (Van Wagner and Pickett 1985; Van Wagner 1987) and archive fire weather data. The FWI System consists of three fuel moisture codes, Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC), and Drought Code (DC), and three fire behavior indexes, Initial Spread Index (ISI), Buildup Index (BUI), and Fire Weather Index (FWI). Calculation of the six components making up the FWI System is based on daily observations of dry-bulb temperature, relative humidity, 10-m open wind speed, and 24-hour accumulated rainfall recorded at 1200 h local standard time (LST) at a suitable weather station (Turner and Lawson 1978). Also computed by the program is the Daily Severity Rating System (DSR), a function of the FWI component as described by Van

Wagner (1970, 1987) and the Cumulative Daily Severity Rating (CDSR) as described by Harvey et al. (1986). The program is based largely on a FORTRAN program written by Van Wagner and Pickett (1985), with some notable input-output exceptions. Fire weather data (measured, forecasted, or estimated) can either be processed from an archived data file or typed in directly. Output from LAPFWI can be displayed in two formats: screen display (from typed-in data only) or print form (if a printer is available).

The second program is LAPFBP (Lap computer Fire Behavior Prediction), which is designed to evaluate fire growth and crowning potential as outlined in the 1984 interim edition of the Canadian Forest Fire Behavior Prediction (FPB) System² (Lawson et al. 1985) with some minor additions. Currently, the primary output of the FBP System is head fire Rate Of Spread (ROS) based on fuel type (14 major Canadian fuel types currently recognized), weather (FFMC and 10-m open wind speed), and topographic slope and aspect. Crowning potential is determined, where applicable, on the basis of the calculated ISI or slope-adjusted ROS. Other outputs include some simple elliptical fire growth model information (Van Wagner 1969): length-to-breadth ratio; area; perimeter length; head, back, and flank fire spread distances; and fire mapping information. Additions to the program not outlined in the 1984 interim edition FBP System include the following:

² Alexander, M.E.; Lawson, B.D.; Stocks, B.J.; Van Wagner, C.E. 1984. User guide to the Canadian Forest Fire Behavior Prediction System: rate of spread relationships. Interim edition. Environ. Can., Can. For. Serv., Fire Danger Group, Ottawa, Ontario.



Government of Canada

du Canada

Canadian Service

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Canadä



Department

Forest Service

Intermountain **Research Station**

General Technical Report INT-GTR-366

December 1997



User's Guide to PCDANGER: National Fire Danger Rating System for Personal Computers

Larry S. Bradshaw Erin M. Law



¹ The exclusion of certain manufactured products does not imply rejection nor does the mention of other products imply endorsement by the Canadian







Equations and FORTRAN Program for the Canadian Forest Fire Weather Index System



Canada

The National Fire-Danger Rating System: basic equations

Jack D. Cohen

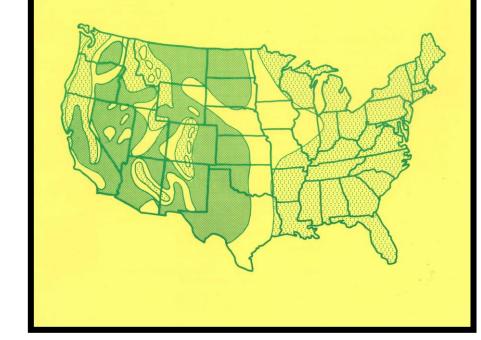
Forest Service

Forest and Range Experiment Station

General Technical Report PSW-82

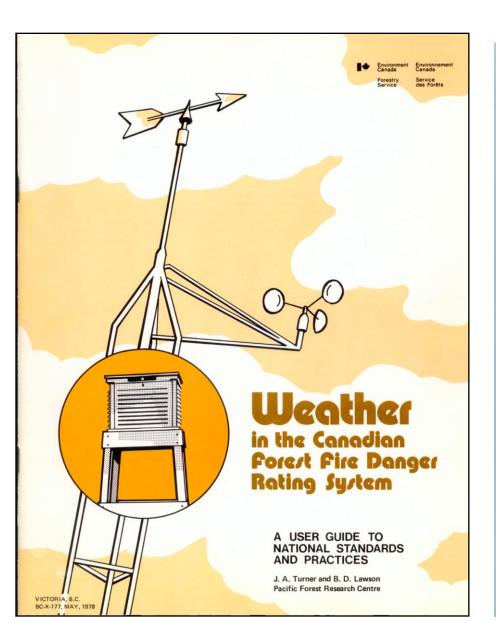
UAS

John E. Deeming









A publication of the National Wildfire Coordinating Group

Sponsored by United States Department of Agriculture

United States Department of Interior

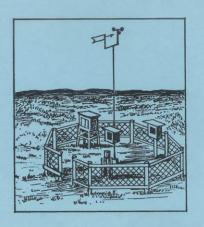
National Association of State Foresters

Weather Station Handbook—an Interagency Guide for Wildland Managers

Arnold I. Finklin William C. Fischer

PMS 426-1 NFES 1140 **MARCH 1990**









by J. A. Turner The Drought Code Component of the Canadian Forest Fire Behavior System Service des Forêts

U.S.D.A. Forest Service Research Paper SE-38

November 1968 Revised November 1988

A Drought Index for Forest Fire Control

U.S. Department of Agriculture-Forest Service Southeastern Forest Experiment Station Asheville, North Carolina



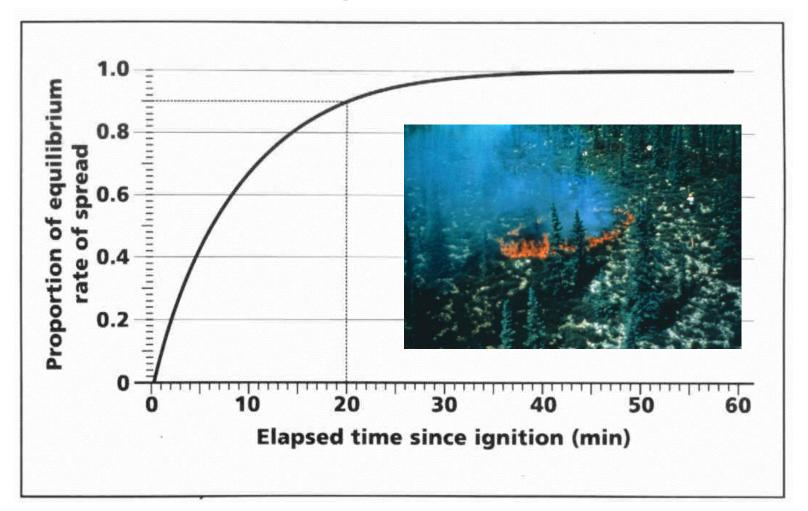
Fire Behavior Outputs



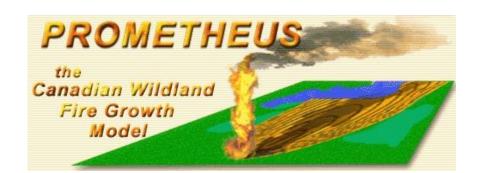
- Canadian
 - Produces Estimates of ROS & Intensity
 - Predicts both Surface &
 Crown Fire Within a
 Given Fuel Type
 - Predicts FuelConsumption
 - Allows for Acceleration
 From A Point Source
 Ignition

- U.S.
 - Produces Estimates of ROS & Intensity/Flame Length
 - Primary Prediction by Fuel Model is for Surface Fire
 - No Estimates of Fuel Consumption
 - No Allowance for Acceleration

Acceleration curve for open canopy fuel types showing the proportion of equilibrium rate of spread as a function of elapsed time since ignition.

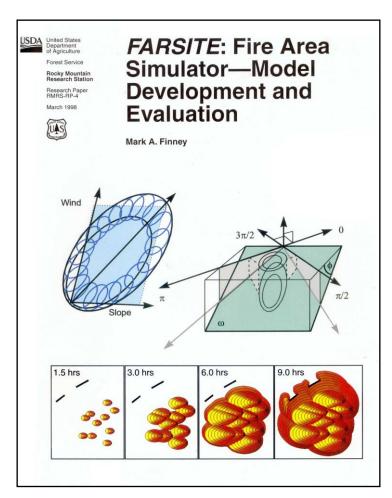






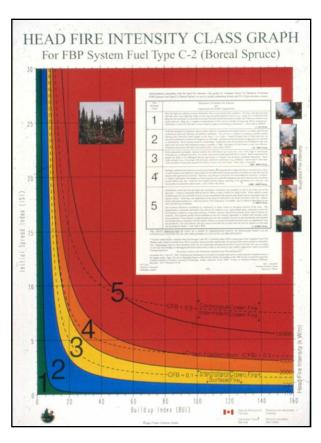
http://www.firegrowthmodel.com/



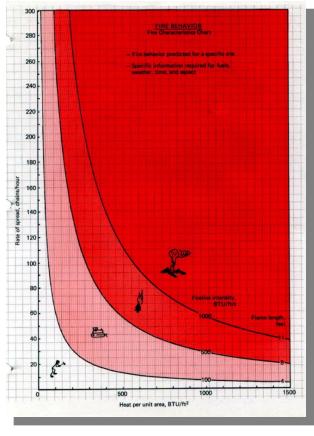


Fire Behavior Outputs: Fire Intensity Class Graphs vs. Hauling Charts









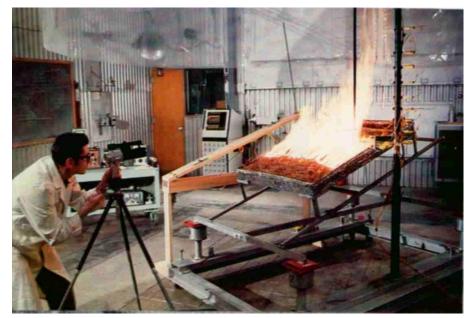


Technical Basis



- Canadian
 - System Largely
 Derived From
 Empirical Data
 Coupled With
 Simple Logic
- U.S.
 - System Based on Laboratory Fires & Physical Theory







In his comparison of the 1972 National Fire Danger Rating System and the Canadian FWI System, Van Wagner (1975) concluded that:

The American system is probably at its best in the open, grassy forests or brush types with little or no duff layer common in many parts of the United States, but not well represented in Canada. The Canadian system, on the other hand, is at its best in forests with fairly complete canopy and a substantial layer of litter and duff but no marked seasonal variation in herbaceous vegetation.







United States Department of Agriculture

Forest Service

Pacific Northwest Forest and Range **Experiment Station**

Research Note PNW-401 October 1982



Predicting Wildfire Behavior in Black Spruce Forests in Alaska

Rodney A. Norum

Abstract

The current fire behavior system, when properly adjusted, accurately predicts forward rate of spread and flame length of wildfires in black spruce (Picea mariana (Mill.)

bserved and quantified, adjustment ted fuel models to correct the lues. Spotting distance models ections and assumptions are made.

The Rosie Creek Fire

Glenn P. Juday

Introduction

The winter of 1982-83 was mild in interior Alaska. Aside from an early, heavy snowfall in October and November which insulated the ground against deep freezing, it was a dry winter as well. The weather station at the Fairbanks International Airport recorded below-normal snowfall from December through March. Breakup came early; the Tanana River at Nenana lost its ice cover on April 29. The average temperature for the month of April 1983 was 7.2°F above normal. By the end of May, the combination of early snowmelt, very low spring precipitation, warm weather, and drying winds produced a high fire danger.

Many people near Fairbanks were looking ahead to a busy construction season or to establishing or expanding cultivated areas. They took advantage of the warm, dry ear ly spring to clear land. Most obtained open-burning permits from the state Division of Forestry (DOF) to burn the slash and clearing debris. Most followed common sense and stopped burning when warm temperatures and high winds caused extreme fire danger after May 28. But on Sunday May 29, a man set fire to his land-clearing debris on the Tanana River lowlands near the mouth of the Rosie Creek Carried by a powerful east wind, the fire escaped and began to race across the highly flammable black spruce-covered permafrost flats, headed west. Above the flats to the north, on the deep wind-deposited silt soils of the south-facing ridges, grew some of the largest and most productive white spruce forests in northern Alaska. The demand for forest products in interior Alaska had made these stands among the most important for forest management in this region of the state. Even more alarming, if the fire shifted to the east, its path would cross a rural residential area that had expanded greatly in population in the last few years.

What follows here is a reconstruction of the events of the Rosie Creek Fire, taken from the fire narrative (Alaska Department of Natural Resources, Division of Forestry, 1983a, b) and fire night reports. The chronology of this fire provides a good opportunity to see how a modern, wildlandfire-control organization works.

*Visiting Associate Professor and Coordinator, Rosie Creek Fire Research Project, Agricultural and Forestry Experiment Station,



tial for making tactical plans for e (Picea mariana (Mill.) B.S.P.)

-Rothermel (1972) fire spread eans of predicting fire behavior. the model, in the form of are not adequately described by the and adaptation of the model are forecast. The typical black spruce/ ens-Pleurozium schreberi) forests of

mographs to predict wildfire vior officer for a fire in an area of Alaska. The fire burned for several rom flat to 32 percent under a a surface fire, presenting an ideal me lengths under varied conditions e availability of an accurate I moisture meter (McLeod 1976) of fuels collected near the fire. nd direction of the wind were lected. Everything necessary to vailable for comparison with values

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Rod Norum found that Fire Behavior Fuel Model 9 Rate of Spread X 1.2 worked best for predicting head fire spread rates in Alaskan black spruce. For flame lengths and in turn fire intensities he recommended using Fire Behavior Fuel Model 5.

1983 Rosie Creek Fire, Fairbanks, Alaska BEHAVE Predictions

Estimating 1-hr Time Lag (TL) Fuel Moisture Content (FMC) as per Rothermel (1983)

Temperature: 74 deg F

Relative Humidity: 33%

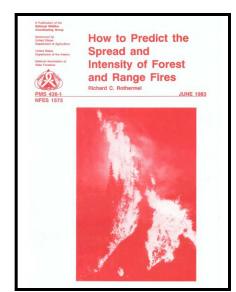
Reference Fuel Moisture: 5%

Adjust for shading, time of year

(i.e., month), time of day,

slope steepness, aspect and elevation: 3%

Dead Fuel Moisture Content: 5% + 3% = 8%



Assumptions (as per Rothermel 1983):

10-hr TL = 8% + 1% = 9%

100-hr TL = 8% + 2% = 10%

Assume 100% for Live Moisture Content as per Rothermel (1983, Table II-2, p. 13)

1983 Rosie Creek Fire, Fairbanks, Alaska BEHAVE Predictions

Estimating the Mid-flame Wind Speed

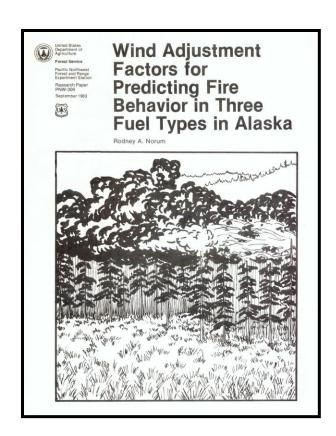
20-ft Open Wind Speed: 13 mph

Rod Norum has suggested a Wind Reduction Factor of 0.2 for Alaskan black spruce.

Dick Rothermel has suggested a Wind Reduction Factor of 0.4 for Fire Behavior Fuel Model 5

Mid-flame Wind Speed = $13 \times 0.2 = 2.6$ mph for Fire Behavior Fuel Model 9

Mid-flame Wind Speed = $13 \times 0.4 = 5.2$ mph for Fire Behavior Fuel Model 5



1983 Rosie Creek Fire, Fairbanks, Alaska



Fire Intensity (Btu/sec-ft):



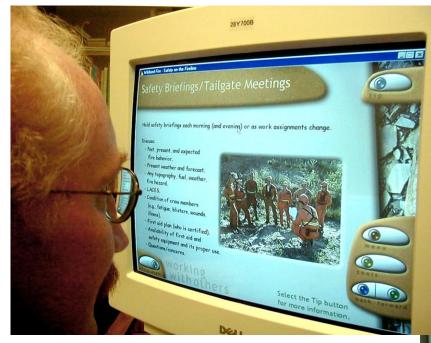
| BEHAVE | CDN FBP |
|---------------|-------------|
| <u>System</u> | System |
| 4 | 103 |
| 3.3 | 34 |
| • | System 4 |

75

12,140



VI. Applications, Training & Software







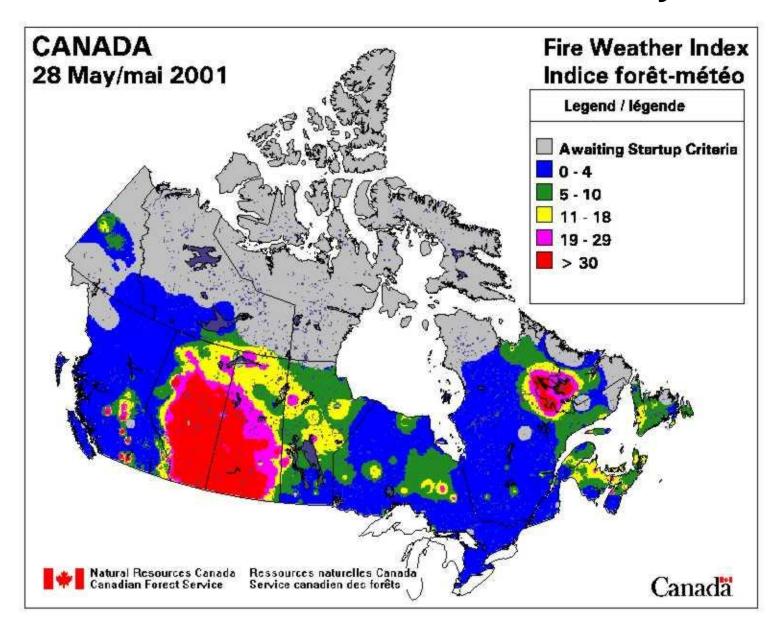


Some Fire Management Applications fire behavior training of the CFFDRS:

- fire behavior training
- prevention planning
- preparedness planning
- detection planning
- initial attack dispatching
- fire suppression tactics & strategies
- escaped fire situation analysis
- prescribed fire planning & execution

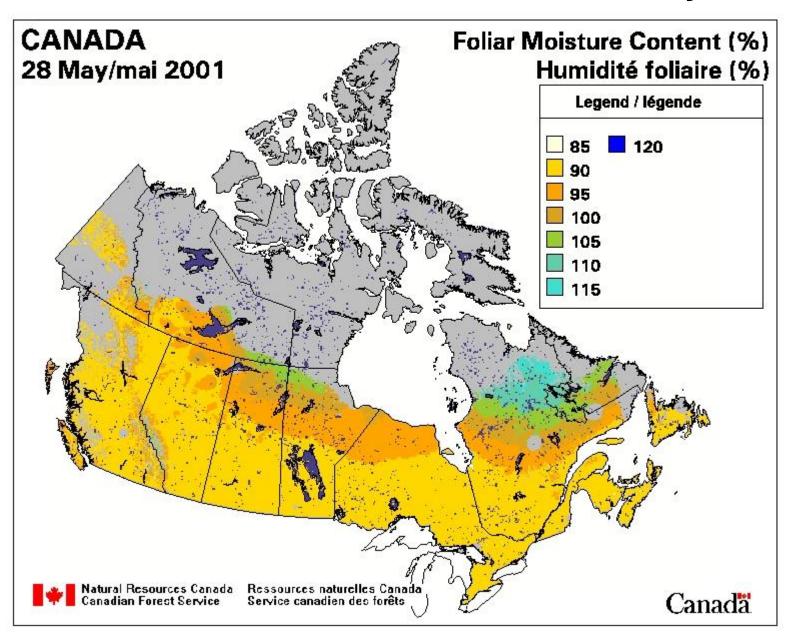


Canadian Wildland Fire Information System



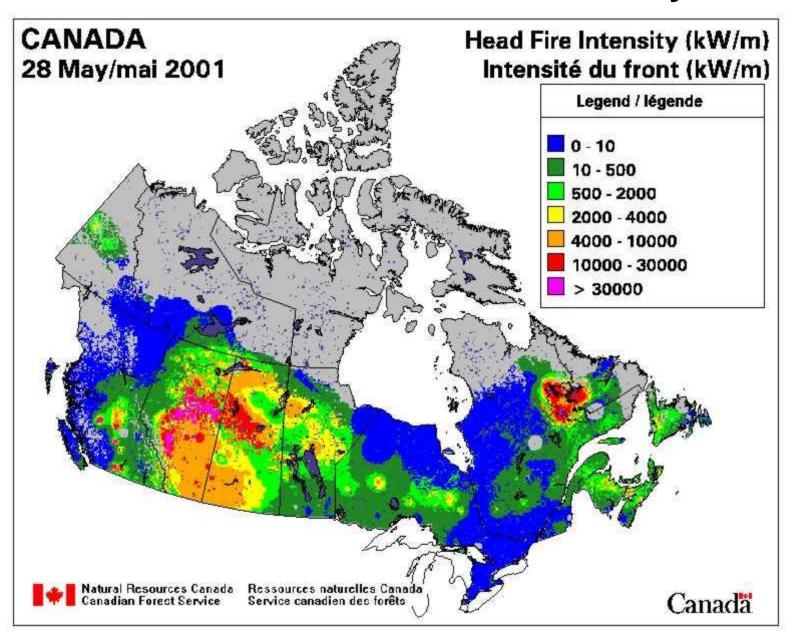
http://fms.nofc.cfs.nrcan.gc.ca/cwfis/

Canadian Wildland Fire Information System

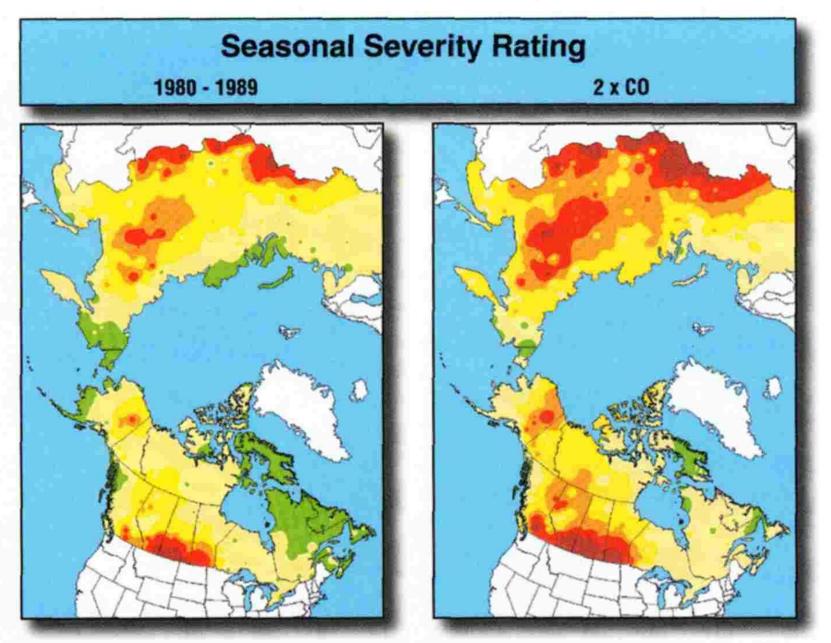


http://fms.nofc.cfs.nrcan.gc.ca/cwfis/

Canadian Wildland Fire Information System

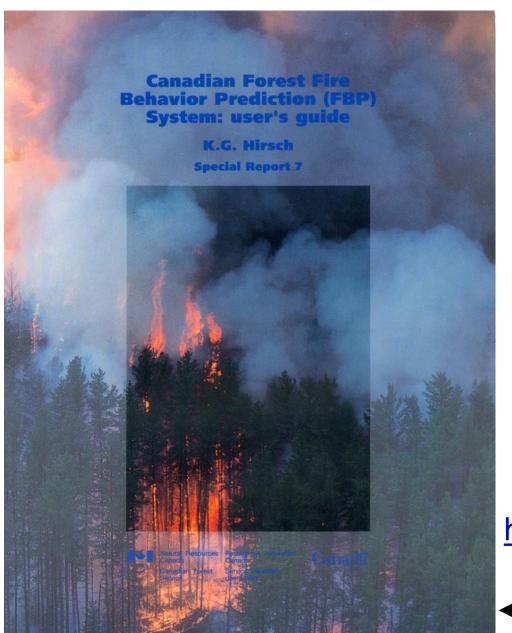


http://fms.nofc.cfs.nrcan.gc.ca/cwfis/



General circulation model-projected changes in circumpolar fire danger levels with a doubling of atmospheric carbon dioxide.

FBP System Training Materials



CD-ROM

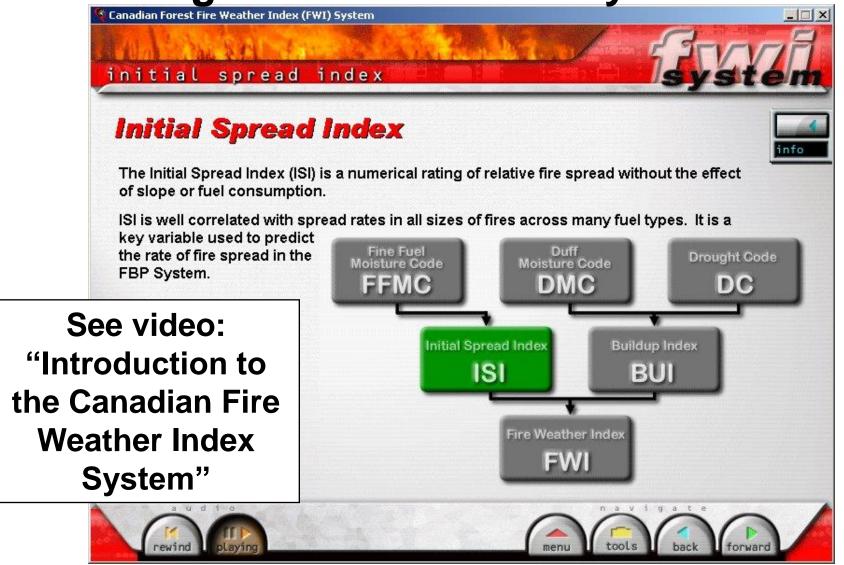


Availability:Raincoast Distributors

http://www.raincoastbooks.com



Understanding the FWI System CD-ROM Training Course available by June 2002



Availability: Raincoast Distributors



Advanced Wildland Fire Behavior Course

Delivered regionally (West, East + French)

Wildland Fire Behavior Specialist Course

Delivered Nationally



Course Dates & Locations Advertised on Canadian Interagency Forest Fire Centre

web site: http://www.ciffc.ca



CFFDRS Commercial Software



http://www.remsoft.com/fire/index.html







VII. Closing Comments PARADOX:

 The models and systems aren't accurate enough.

 The models and systems are too complicated.

from Rothermel (1987)

Presumably, crude but reliable decision aids are needed at the field level.





Blackstone Prescribed Burn in Bog Birch Shrubland Fuels, west-central Alberta - October 11, 1991

Observations by Bill de Groot (Canadian Forest Service, Edmonton, AB)

Temperature: 19 C (66 F)
Relative Humidity: 21%
Wind measured at a height
1.3 m (4 ft) in the "open":
10.9 km/h (6.8 mph)



Observed Rate of Fire Spread (3-min interval): 21.9 m/min (71.8 ft/min)

Blackstone Prescribed Burn in Bog Birch Shrubland Fuels, west-central Alberta - October 11, 1991

BEHAVE PREDICTIONS

1-hr TL FMC = 5% 10-hr TL FMC = 5% + 1% = 6% Live Woody Moisture = 50%

(as per Rothermel 1983, p. 13, Table II-2)

Fuel Model 5 - Brush (2 ft)

Predicted Rate of Spread: 22 m/min (71.2 ft/min) Predicted Flame Length: 3.1 m (10.2 ft)

THE END



ANY QUESTIONS?